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The subject vessel is a concept ship conceived by CDIM-SDD that can easily transform itself to operate either as a Catamaran, a SWATH, or as an SES. The catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping, and the SES because of its ability to afford shallow draft with cushion end seals deployed for gaining access to Austere Ports, and to combine with the SWATH to enhance seakeeping at low speed fore transferring cargo to and from a sea base in heavy seas. This latter combination is achieved by ballasting the vessel to transform from a Cat mode to a SWATH mode in combination with deploying the cushion end seals and a mid-cushion divider, and supplying air to the cushion as in an SES with active control of cushion air flow and, hence, control of cushion pressure fore and aft of the divider that provides significant dynamic control of ship pitch and heave in a seaway.

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# CONCEPT DESIGN REPORT FOR A LOW DRAFT STABILIZED – HIGH SPEED CONNECTOR (LDS-HSC) VESSEL

## FOR

## THE ONR HIGH SPEED SEA LIFT (HSSL) PROGRAM

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Marine

# Foreword

This report has been prepared by CDI Marine Systems Development Division (CDIM-SDD) of Severna Park, Maryland under contract No. 00014-06-M-0156 to the U.S. Navy's Office of Naval Research (ONR). The report describes the concept design of a large high-speed Roll-On / Roll-Off (RO/RO) cargo ship developed in support of the ONR High-Speed Sea Lift (HSSL) Subtopic-B Program of work described in ONR BAA No. 05-007. The Program Manager and sponsor at ONR was Dr. Patrick Purtell, ONR Code 331, and the principal point of contact at CDIM-SDD was David Lavis. The program manager at CDIM-SDD was Volker Stammnitz with technical support from the staff at CDIM-SDD, principally Greg Buley and Chris Clayson.

# Executive Summary

This report describes a concept ship designed by CDI Marine Systems Development Division (CDIM-SDD) located in Severna Park Maryland. The design was developed for the U.S. Navy's Office of Naval Research (ONR) as part of their High-Speed Sea Lift (HSSL) program solicited under ONR Broad Agency Announcement (BAA) #05-007. The design was started initially by CDIM-SDD while under subcontract to SAIC in Annapolis, Maryland, who, in turn, were under contract to ONR in response to the BAA's Subtopic-B program of work that focused on improving "Computational Approaches & Hydrodynamic Tools" for future ship designs.

The subject vessel is a concept ship conceived by CDIM-SDD that can easily transform itself to operate either as a Catamaran, a SWATH, or as an SES. The catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping, and the SES because of its ability to afford shallow draft with cushion end seals deployed for gaining access to Austere Ports, and to combine with the SWATH to enhance seakeeping at low speed for transferring cargo to and from a sea base in heavy seas. This latter combination is achieved by ballasting the vessel to transform from a Cat mode to a SWATH mode in combination with deploying the cushion end seals and a cushion divider, and supplying air to the cushion as in an SES with active control of cushion air flow and, hence, control of cushion pressure fore and aft of the divider that provides significant dynamic control of ship pitch and heave in a seaway.

All these modes of operation were tested by CDIM-SDD with a scale model of the concept ship at the David Taylor Model Basin at Carderock, Maryland, in December of 2006. Testing of the HSSL model was very successful. It demonstrated the ability to achieve the desirable full-scale draft goal and the ship's resistance as a Catamaran was very repeatable and provided a good database for verifying ship powering predictions. In the SWATH mode, the motions of the model were excellent – 1.1 feet of RMS heave in sea state 5 and 3.2 feet in sea state 6. These motions may be low enough for RO/RO operation without the need for motion control. SES motion control was encouraging, but could have benefited significantly with more time devoted to tuning the control system. Selected video clips of several of the test runs are contained in Appendix B of the test report. Results of the model tests were fed back to refine the concept design as reported herein.

The characteristics of the ship that ONR considered to be desirable were taken as a goal to guide the design and they are listed here for reference. Some goals were to be considered hard while others were soft as shown here. The desired payload capability of being able to carry 4000 short tons was certainly viewed as a hard goal and required research into some of the Sea Power 21 open source documents to determine what actually constituted that value. It turned out that this represents a Stryker Battalion Task Force (BnTF), a subset of the Brigade Combat Team/Unit of Action (BCT/UA), a pivotal component of the U.S. Army's Modular Force. Details of this force component were used to define the selected payload for the design.

**Table 1-1 – Overview of HSSL Desired Capabilities**

| Parameter | Numerical Value | Type |
|---|---|---|
| Displacement | ≤ 12,000 tons | Soft |
| Length | ≈ 560 feet | Soft |
| Payload | ≈ 4,000 tons | Hard |
| Sustained Transit Speed | ≥ 43 knots | Hard |
| Unrefueled Range at Transit Speed | ≥ 5,000 nautical miles | Hard |
| Draft at Port Entry | ≤ 6.5 meters | Hard |
| Special Capability – Load Transfer | Drive vehicles from ship-to-ship | Hard |
| Special Capability – Air Capable | Undefined capability | Soft |
| Full Performance Weather Limit | ≥ Sea State 4 | Hard |

In response to these goals, a ship was evolved through various iterations and trade-off studies that examined steel and aluminum structure, various types of power plants and power distribution systems, waterjet propulsor options and several different configurations for below water hull geometry in an attempt to reduce ship drag and powering requirements.

The leading particulars of the final design that meets all of the hard and soft goals shown in the table above are as follows:

**Table 1-2 – Leading Particulars of Final Design**

| Particular | Value |
|---|---|
| **Full-Load Weight, LT** | **19,743** |
| **Lightship Weight, LT** | **8,506** |
| **Total Installed Power, SHP** | **402,306** |
| **Power Plant** | **Integrated Power System (IPS) featuring:**<br>• (6) 50 MW Rolls-Royce MT50 based Gensets<br>• Associated Conversion and Distribution Systems<br>• (6) 50 MW High Temperature Superconducting (HTS) Propulsion Motors |
| **Propulsors** | **Axial-Flow Waterjets** |
| **Hull Structure & Super Structure** | **Aluminum Alloy** |
| **Overall Length, Ft** | **580.0** |
| **Overall Beam, Ft** | **134.0** |
| **Full-Load Draft as Cat, Ft** | **28.8** |
| **Full-Load as SES, Ft** | **< 21 Ft. (6.5 m)** |

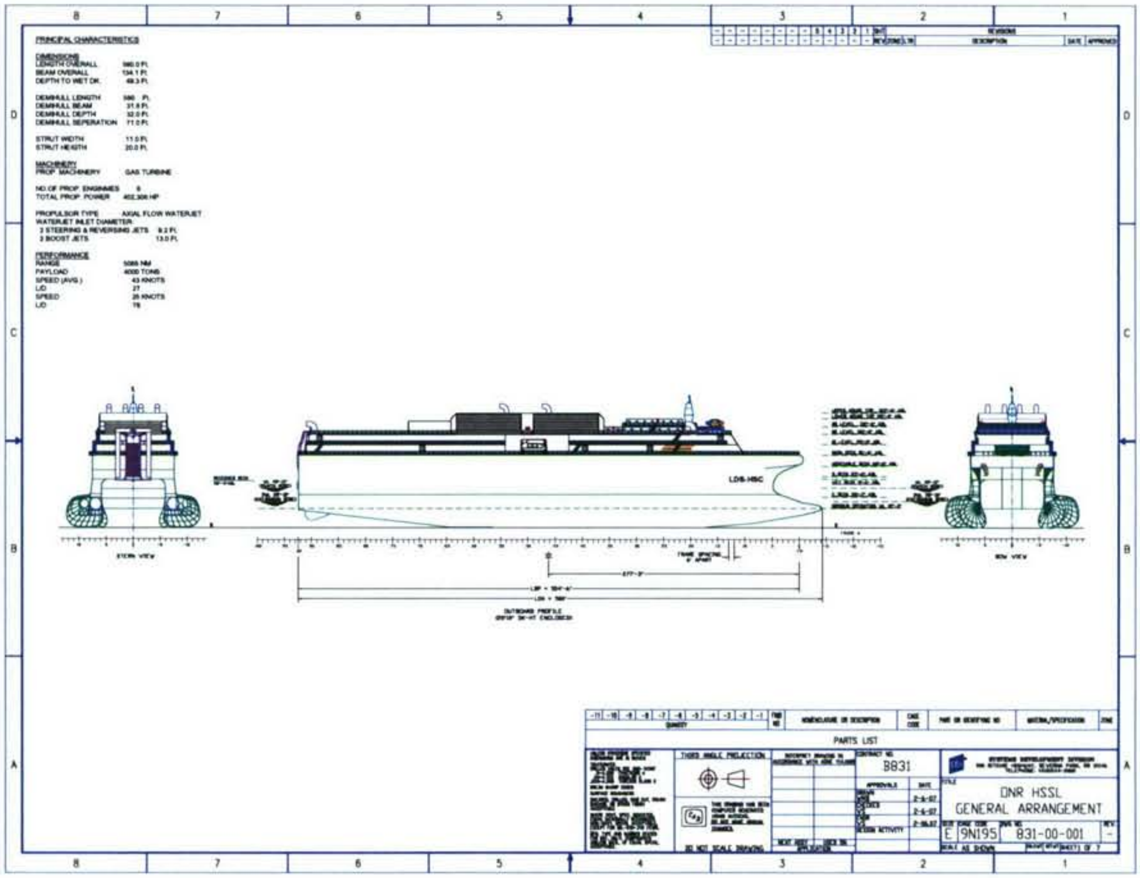
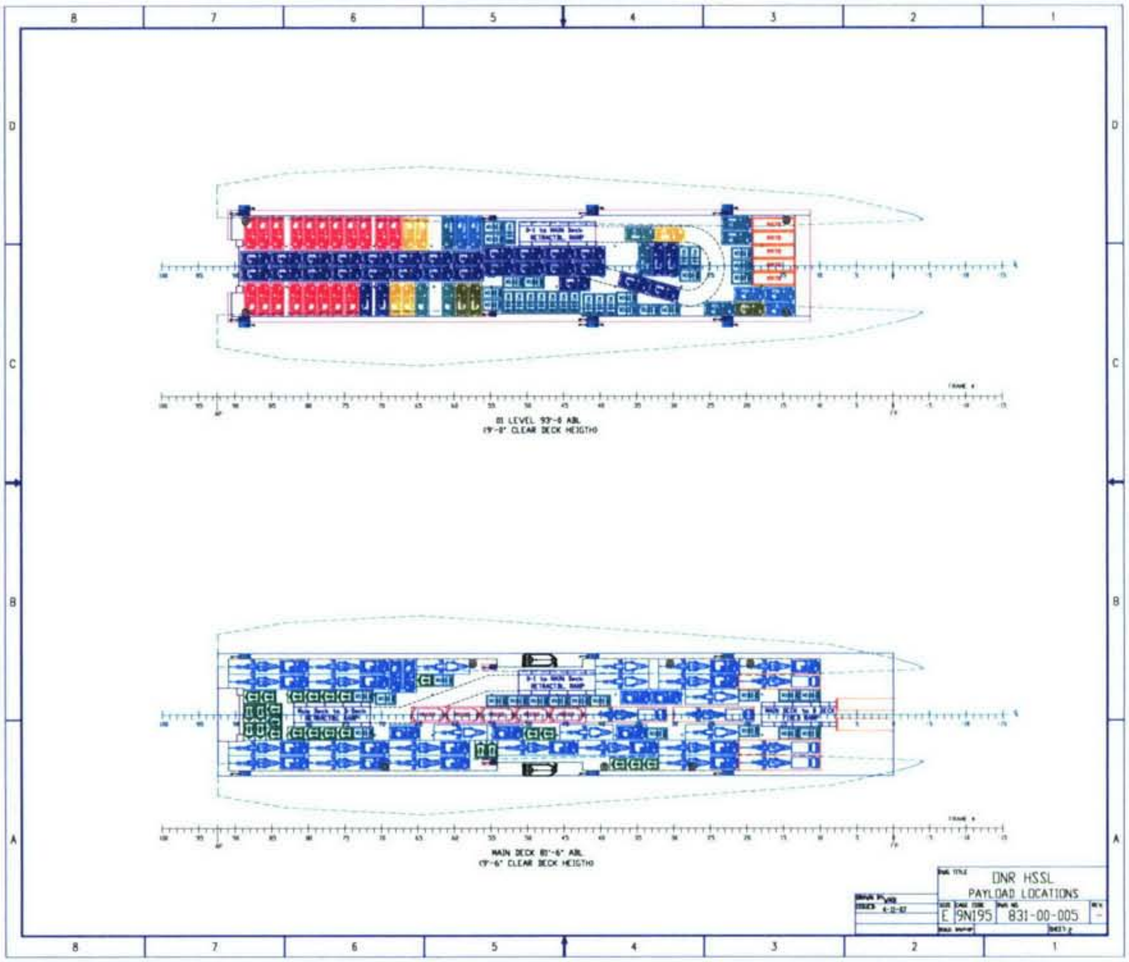



**Figure 1 – General Arrangement Outboard Profile**

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# 1 Introduction

This Final Design Report sets forth the results from additional analysis work that was performed to further the design of the CDI HSSL Concept, which was initially developed under the SAIC Phase-I Austere Access High-Speed Sealift Topic B Project.

## 1.1 Background

A unique high-speed Sea Base Surface Connector Concept Vessel was initially conceived in late 2005 by CDIM-SDD for ONR under the SAIC ONR HSSL Subtopic-B program. The objective of this initial effort was to create a conceptual design of a vessel that would challenge the ability of the tools being expanded and integrated for ONR, under the Subtopic B program of work, to predict ship hydrodynamic loads, motions and performance. This initial conceptual design was developed using minimum funding over a short period of time to support an aggressive schedule for hydrodynamic tool development. This concept vessel was, however, used in Phase-II of the SAIC HSSL Subtopic B program in which model tests were conducted to provide ship motion and resistance data for the purpose of tool validation. Thus, the present effort described herein is to further develop the initial concept in order to improve the design and establish a greater level of confidence in the validity of vessel characteristics such as structural arrangement, powering and engine and propulsor selection, ship stability, ship internal configuration and arrangement, design of cushion seals, lift-air supply system for the cushion, ballasting and de-ballasting, and more reliable subsystem weights and costs for SWBS groups 1 through 7. As will be seen in this report, the improvements achieved included the hydrodynamics of the ship's below-water shape that was evolved in conjunction with the use of tools being enhanced and validated by SAIC under their Phase-II program of work. Results of this work were documented and delivered in time to influence the configuration and mass properties of the model that was designed, built and tested at NSWC Carderock as part of the SAIC Phase-II ONR HSSL program of work. Similarly, the results of the model tests became available in sufficient time to influence the design described in this report.

## 1.2 Ship Concept

A serious challenge for supporting and sustaining the operations of military marine expeditionary forces ashore will be the safe, reliable and efficient transfer of heavy equipment and cargo at sea from a Sea Base, or MPF(F) Ship, to high-speed surface connectors (such as the ONR HSSL) for shipment of cargo to forces ashore via shallow-draft ports. One of the primary issues is the need to mitigate wave-induced relative motions between ships in sea states 4/5 to enable safe and rapid heavy vehicle transfer (loading-unloading heavy armored combat vehicles) between ships at sea. This has been recognized as a serious challenge by the U.S. Navy, and numerous techniques have been, and are being, tried with mixed success so far. This challenge is in addition to the challenge of efficiently transporting very large payloads at high speeds over very long distances at sea with a ship that can gain access to shallow draft ports. The objective of

the program of work discussed in this report is, therefore, to conceive of a near-term, affordable, shallow-draft, heavy-lift, High-Speed Surface Connector (HSC) that will make motion compensation requirements, for systems now being developed for cargo transfer, less demanding and therefore have a higher probability of success in satisfying overall Sea Basing mission objectives.

The problem is that there are no existing types of high-speed ships that can achieve this objective because notionally the HSC should ideally: (i) be capable of efficiently transporting very large payloads (4000 tons) at high speeds (greater than 40 knots) over long distances (greater than 5000 nautical miles); (ii) have shallow draft to permit access to as many foreign ports as possible; (iii) have low pitch, heave and roll motions in response to heavy seas; and (iv) require reliable low-risk technologies that can result in a viable near-term affordable solution.

To achieve this capability, a multihull is probably best suited to solve problems (i) and (iv), an SES best for problem (ii), and a SWATH for problem (iii). However, no ship is best for all unless a viable hybrid of all three can be conceived. Thus, the concept ship conceived by CDI in support of SAIC's Phase-I of the ONR HSSL Subtopic B program of work looks at combining all three and, at first examination, it would appear that there is a significant opportunity for the attributes of each concept to synergistically work together to produce a vessel that is operationally transformable to be far superior for each element of the mission than any of the three original concepts alone.

The concept is a vessel that can easily transform itself at sea to operate either as a Catamaran, a SWATH, or an SES. The Catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability, and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping. The SES was chosen because of its ability to afford shallow draft with end seals deployed and to combine with the SWATH to enhance seakeeping at low speed. This latter combination is achieved by ballasting the vessel to transform from a Cat mode to a SWATH mode, in combination with deploying the cushion end seals and a cushion divider, and supplying air to the cushion as in an SES with active control of cushion vent valves fore and aft of the divider. This takes advantage of the very large aerostatic forces and moment arms available from the SES split cushion to actively control heave and pitch motion from relative-motion feedback on a hull that already has reduced seaway excitation forces from the Small Waterplane Area SWATH mode. This concept for SES has already seen limited demonstration by NSWCCD. The combination of ballasting/de-ballasting and end-seal deployment to control draft offers the ability to also adjust deck height and to detune the ship's response as it is being loaded or unloaded. Active roll control could also be arranged, if needed, with the addition of an inflated longitudinal keel. De-ballasting can be assisted with SES cushion pressure. Alternatively, a system to actively vector waterjet thrust could be used for roll motion control.

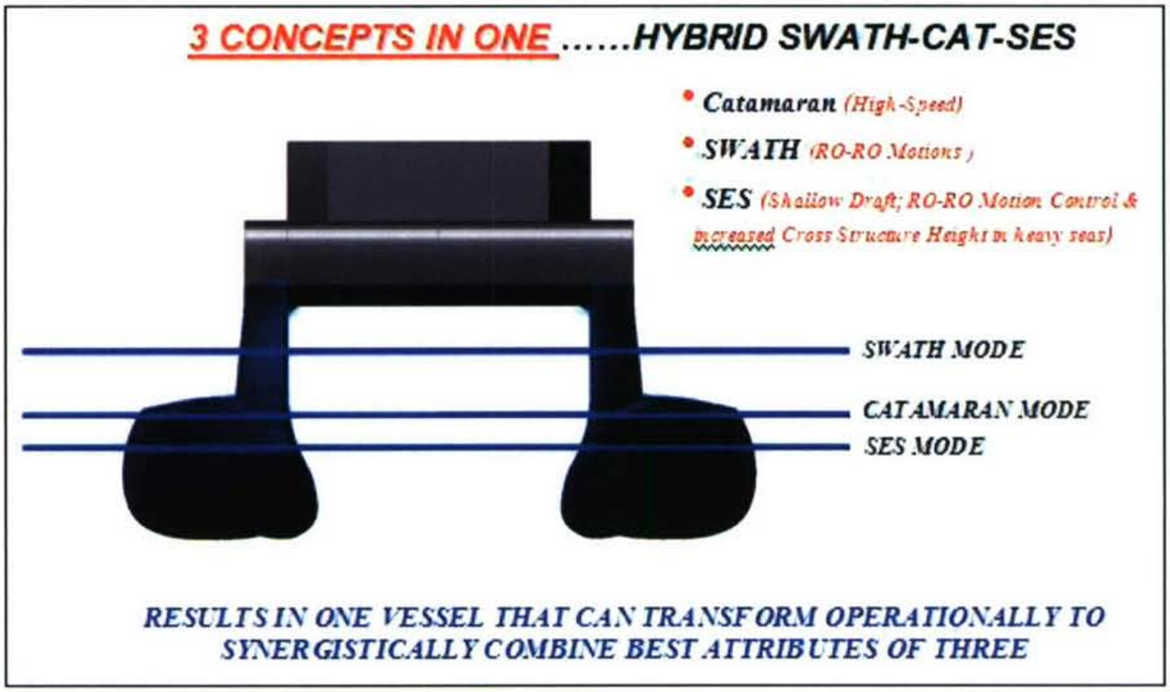


**Figure 1-1 – Modes of Vessel Operation**

The approach could be used for loading at zero forward speed alongside the Sea Base or for low-speed "ship-stern-to-HSC-bow" loading when the HSC is being towed in a partial self-propelled mode with maneuvering control at a most favorable heading to the sea. Note that this is a concept not available to non-air-cushion type vessels, which generally need significant forward speed through the water to achieve useful vertical plane motion control. Note also that at no time are the SES seals used for high speed, so their life expectancy should not be a major issue.

## 1.3 Assessment of HSSL Performance Goals

It is very desirable that the HSSL connector be capable of achieving the performance goals specified by ONR in the HSSL BAA. In this task, we examined the feasibility of these goals relative to the current and projected feasible state-of-the-art to see if a less demanding set of goals would be a more reasonable choice for further development of the concept. As a result, a decision to not change the Performance Specification for further work was made and reported to ONR.

# 2 Project Approach and Initial Concept Designs

## 2.1 Project Objectives

Guidance provided by the Office of the Secretary of Defense (OSD), known by the rubric "10-30-30", cites goals for the speeds at which forward deployments must be executed. These goals cannot be met with existing transportation vehicles, particularly the ships on which over 90% of the material needed by ground forces has to move. This capabilities gap is magnified by the prospect of abandoning our forward bases and stationing our forces in the Continental United States (CONUS).

Several studies and activities conducted by the U.S. Navy have examined the feasibility of High Speed Sealift (HSSL) connectors to carry large payload weights at high speed over transoceanic distances. It is clear that the performance requirements dictated by the "10-30-30" philosophy cannot be met by "conventional" ships. In many instances, these studies have indicated that the feasibility of achieving the appropriate speed, payload capability, and range requires the application of advanced technologies such as novel hullforms and lightweight structures. Furthermore, the capability of rapidly transferring heavy loads between ships in the open ocean in Sea State 4 (SS 4) conditions must be addressed to support a fully functional system-based approach for in-theater cargo delivery.

In addition to the already demanding challenges on the Hull, Mechanical, And Electrical (HM&E) systems in HSSL-type vessels, the capability to work through "austere" ports is also vitally important. This requires the capability of morphing into a shallow-draft configuration upon port entry, and potentially performing offload operations autonomously.

Specific ship performance goals are currently being developed in the Army and the Marine Corps communities. However, finalization of these performance targets can only be achieved in consultation with industry, as it is vitally important to understand not only the technological limitations on the ultimate set of requirements, but also to quantify the costs associated with these capabilities.

Early feedback from the end-users of HSSL indicates that the interface of greatest impact in this regard is the matter of exploiting small ports; all other things being equal, the largest possible ship would be wanted -- and there is certainly an interest in being able to carry at least a battalion, which means a payload of 3,500 to 4,000 tons. However, a wide choice of ports is also wanted, and that constitutes a downward pressure on ship size. Keeping uncertainties like these in mind, a rough and tentative estimate of desired mission capabilities has been provided by the Office of Naval Research (ONR), as summarized in Table 2-1.

**Table 2-1 – Overview of HSSL Desired Capabilities**

| Parameter | Numerical Value | Type |
|---|---|---|
| Displacement | $\leq$ 12,000 tons | Soft |
| Length | $\approx$ 560 feet | Soft |
| Payload | $\approx$ 4,000 tons | Hard |
| Sustained Transit Speed | $\geq$ 43 knots | Hard |
| Unrefueled Range at Transit Speed | $\geq$ 5,000 nautical miles | Hard |
| Draft at Port Entry | $\leq$ 6.5 meters | Hard |
| Special Capability – Load Transfer | Drive vehicles from ship-to-ship | Hard |
| Special Capability – Air Capable | Undefined capability | Soft |
| Full Performance Weather Limit | $\geq$ Sea State 4 | Hard |

ONR has also provided some supplemental guidance in addition to those notional requirements identified in Table 2-1, which can be summarized as follows:

It is presumed that the speed goal stated in Table 2-1 will result in a Froude number in excess of 0.5 and, consequently, that a multihull configuration is likely.

It is also presumed that the port-entry draft required by Table 2-1 is too small to be consistent with other vessel characteristics and, consequently, that the hullform will have to morph into a low-draft configuration at port entry. It has been suggested that this might be accomplished by lowering curtains fore and aft on a catamaran, converting it into an SES, and/or by building inflatable ballast tankage into a catamaran's underwater structures.

At-sea load transfer of heavy point loads (such as M1 tanks) is a capability that is needed, and to satisfy the "10-30-30" edict, it has to be accomplished at a speed that precludes cranes or high-lines. It is believed that the vehicles will have to be driven from one ship to another, which requires a scrupulous matching of the heave, pitch, and roll motions that probably includes some form of dynamic control.

Finally, ONR notes that airborne activity is playing an ever-increasing role in littoral warfare, and that some provision will have to be made for that eventuality in any ship concept developed in support of the HSSL program. The specific capabilities required in this area are utterly without definition at the present time, but are believed to require that at least the weather deck be free of obstacles like islands.

This is a highly demanding set of desired capabilities, and in addition to the development of new and innovative concepts in naval architecture and design, achieving this set of performance capabilities also requires advances in our ability to accurately predict complex hydrodynamics effects, such as the dynamic structural loads inherent to non-traditional hullforms operating in high sea states at high speed.

## 2.2 Overview of HSSL Concept

The design described in this report was initially developed by CDI as part of an ONR BAA Subtopic B program of work performed by a team headed by SAIC. Although the primary focus of the "Subtopic B" effort related to the development and evaluation of a state-of-the-art suite of high-fidelity computational tools, it was necessary that these tools be exercised on a design concept that had a high likelihood of complying with the desired performance goals specified in Table 2-1. This was necessary in order to ensure the validity and accuracy of the tool-set for the HSSL application.

As such, CDI Marine – Systems Development Division (CDIM-SDD) developed an innovative hybrid Catamaran/SWATH/SES design configuration in order to satisfy the need for high-speed transit, full operation in waves, at-sea cargo transfer, and the ability to service austere ports. This HSSL concept, shown in Figure 2-1 and Figure 2-2, offers an innovative way of readily transforming it's configuration between three primary modes, including operation as a:

- ***CATAMARAN*** when high speed is most important, such as during normal transit in low to moderate seas,

- ***SWATH*** (Small Waterplane Area Twin Hull) when reduced motions in waves are most important, such as during load transfer at sea, or when conducting air operations, and finally, as an

- ***SES*** (Surface Effect Ship) when (i) shallow water draft is most important, such as when entering certain ports, or when (ii) dynamic motion control is required during air operations or cargo transfer at sea.

The SES configuration would be achieved using retractable end seals and mid-cushion seals that create a compartmented cushion between the hulls. Because the SES's end and mid-cushion seals will be deployed for only a small amount of time, the traditional problem of seal wear will be significantly mitigated. Likewise, since the SES mode will only be used at low speed during (i) air operations or cargo transfer at sea, (ii) shallow draft port operation, and (iii) when beaching, the lift air supply and powering system will be minor compared to that required for normal high-speed SES. The concept of transforming the HSSL to an SES for the high-speed ocean transit mode was considered to be too great a challenge for such a large ship.

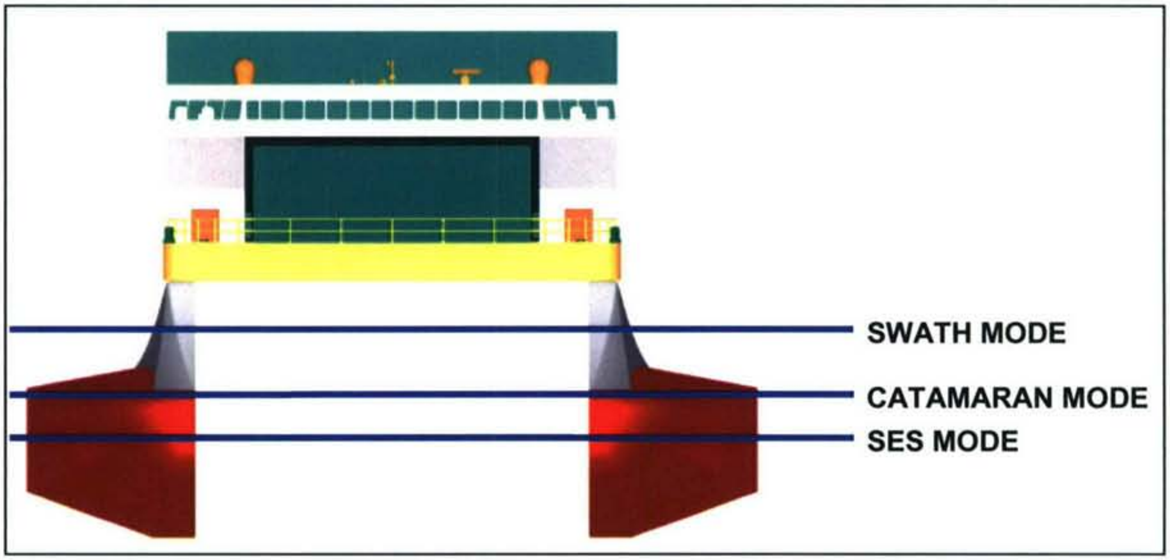


**Figure 2-1 – Section View of HSSL Concept Showing Waterlines for Various Modes of Operation.**

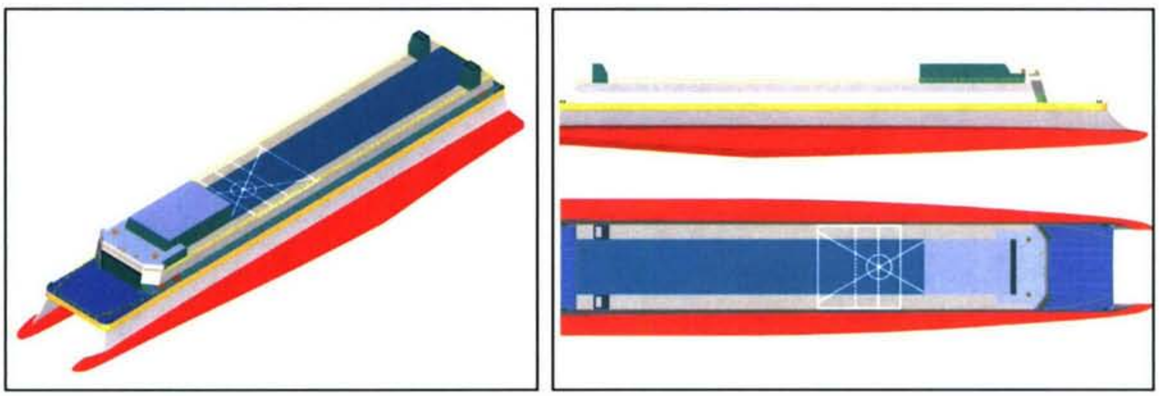

**Figure 2-2 – Isometric, Profile, & Plan Views of HSSL Concept**

The SWATH configuration is achieved by taking on saltwater ballast such that the demihulls are completely submerged, resulting in a substantial reduction in waterplane area and a corresponding reduction in seaway induced excitation forces. The lift system already in place to support the SES mode of operation can also be utilized to supplement the ballasting/deballasting operation, thereby increasing the speed at which the HSSL concept can covert between differing modes of operation.

Note also in Figure 2-2 that the HSSL concept proposed offers a large unencumbered deck area from which to support air operations. Additionally, the exhaust funnels currently shown at the aft end of the deckhouse top could easily be relocated to discharge over the side, or over the stern, to free up additional deck area if a capability other than (or in addition to) Vertical Take Off and Landing (VTOL) is envisioned.

Although all of the capabilities envisioned for the HSSL application are very demanding from a design and analysis standpoint, it is speculated that the at-sea transfer of point loads will be the most challenging requirement to realize in practice. In this area, CDIM-

SDD has again proposed an innovative and promising solution, taking advantage of the unique hybrid HSSL design. In this concept, the HSSL is intended to follow in the wake of the seabase ship at the best combined speed and heading to the sea to minimize relative motions. The HSSL would remain under power to maintain steerability, but would also be partially towed by the seabase ship (LMSR/MPF) with specially-designed energy-absorbing tension lines for low-risk, positive stationkeeping. This concept is illustrated in Figure 2-3.

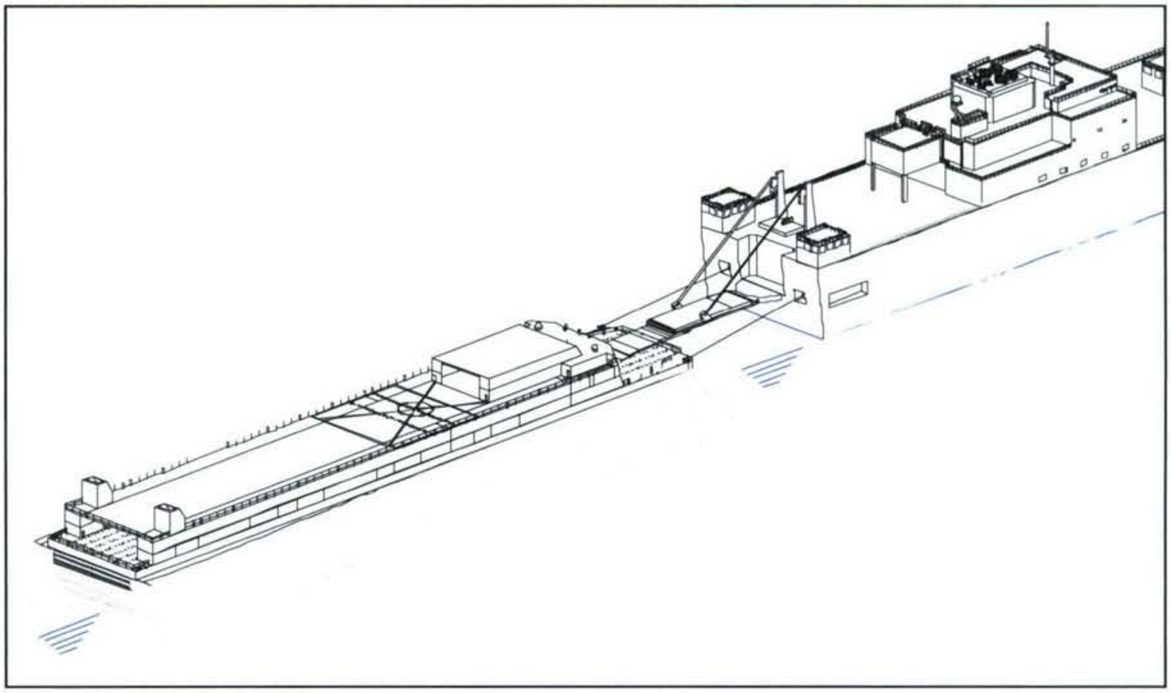

**Figure 2-3 – Concept for RO/RO Transfer of Cargo Loads at-Sea.**

In addition to the use of constant-tension winches and operation on best heading, the hybrid HSSL configuration proposed herein offers the potential to leverage additional aspects of the design to further improve the potential for successful at-sea cargo transfer, including:

- supplementing the HSSL's SWATH mode with a partial cushion SES, using a compartmented cushion system with a dynamically-controlled cushion venting system to take advantage of the very large forces and moments available from aerostatic pressure for static trim and dynamic pitch, heave and roll motion and position control, and

- the use of dynamically-controlled vectoring waterjet nozzles to further reduce the pitch and roll motions of the HSSL during cargo transfer.

Although it is recognized that the bow-to-stern concept for at-sea cargo transfer represents a deviation from parallel studies and evaluations being performed in support of the larger sealift/seabasing problem, there are several distinct advantages associated with the strategy proposed, including (i) a reduction in the number of mooring cables required

and a complete elimination of the need for fenders, (ii) a reduction in the fore-and-aft deck area required to land the seabase ship's ramp foot, (iii) an easy procedure for emergency release, (iv) an easy linear "drive-through" distribution of vehicles on the HSSL ship with limited requirements for vehicle maneuvering, and (v) the fact that it is possible to lower a seabase/LMSR stern ramp in a seaway, while the ability to successfully deploy a side-port ramp in seaway conditions is questionable.

Note that ONR had emphasized in the original Broad Agency Announcement (BAA #05-007) for this HSSL program of work that "the users' requirements had not been fully-developed; as they do not know just what performance characteristics are achievable and, especially, the rules that govern the trade-off inter-relationships. Thus, the goal of Subtopic B was not to define a set of specific performance characteristics but rather to define the volume accessible to the users in the performance hyperspace of interest to them". ONR goes on to state that "the importance of the parametric studies needs to be stressed" and that this effort "needs to identify broad capabilities and potential hurdles, and not just perform a point design". These goals were reinforced and restated at the kick-off meeting held on 22 November 2005.

However, in this context, the differences between the goals of Subtopic A and Subtopic B of the BAA must be emphasized. As ONR states, "the focus of Subtopic B is the hydrodynamic performance" and the accurate prediction thereof using state-of-the-art high-fidelity analytical tools. In order to properly exercise and evaluate these tools, it is necessary that information approaching a "point design" be available, including faired hullform geometries, mass properties, etc. As such, CDIM-SDD was tasked to develop a viable HSSL ship configuration (i.e. a point design) that is likely to meet the performance characteristics identified in Table 2-1, using the catamaran/SWATH/SES concept described in the following Section 1.2 as a baseline.

## 2.3 Initial Baseline Design

To support the design development, limited parametric studies were first carried out utilizing CDIM-SDD's whole-ship design synthesis software ComPASS$^{TM}$, which is described further in the paragraphs that follow and also in Section 3.4.1. These parametric studies were necessarily restricted in scope by the constraints of time and budget in comparison to the parallel Subtopic A efforts, which were entirely focused on architectural concepts. The goal was to provide a viable, balanced design solution early-on in the project to support the testing and evaluation of the advanced computational tools at the heart of the Subtopic B effort.

Specifically, ComPASS$^{TM}$ was utilized to explore the feasible design space that surrounds the desired HSSL operational and performance characteristics defined in Table 2-1, and to identify and define the appropriate geometrical, operational, and performance limitations that can be used to establish the boundaries of acceptable solutions. The HSSL design space was visualized using a series of surface plots that have various limiting criteria placed directly on the surface plot, an example of which is shown in Figure 2-4.

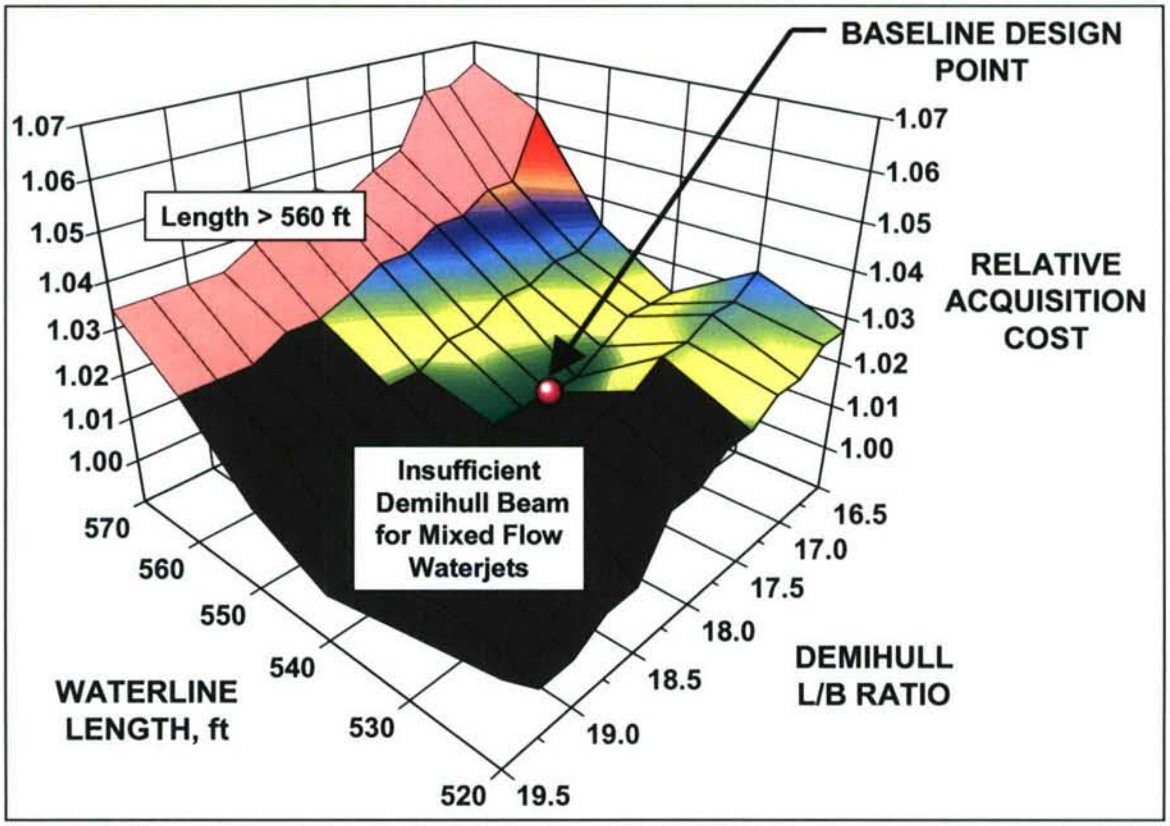


**Figure 2-4 – Solution Space for the Hybrid Catamaran/SWATH/SES HSSL Concept**

Figure 2-4 shows a representation of the relative acquisition cost of the HSSL concept on the vertical axis as a function of the geometric properties of the hullform, in this case waterline length and demihull length-to-beam ratio. Although issues of cost have not been emphasized heavily in this particular BAA, relative acquisition cost is chosen as a design discriminator here since it is usually a good indicator of balance between minimized weight and minimized power requirements. The color-mapped area of the surface in Figure 2-4 is tied to the acquisition cost as well, with green indicating lowest costs and red indicating highest cost. Certain portions of the solution space are also blocked out as unrealistic because (i) vessel length is in excess of the ONR targets, and (ii) there is insufficient demihull breadth to accommodate the installation of the required mixed-flow waterjet propulsion system in the transom. Although the second of these issues can be mitigated through the use of advanced axial-flow waterjets, which are smaller and lighter for an equivalent power capacity, design development in this case has focused on technology which is currently available in lieu of developmental items. Also identified in Figure 2-4 is the initial baseline design point selected for the HSSL concept.

The basic particulars and machinery characteristics of the initial baseline design point are shown in Table 2-2. According to the ComPASS™ predictions, the design requires four gas turbines of approximately 36 MW capacity driving four 225 cm mixed-flow waterjets to achieve the performance targets outlined in Table 2-1. Figure 2-5 gives the

ComPASS™ generated brake horsepower estimate, showing an anticipated top speed of 43.1 knots in sea state 4 conditions at 100% of the engines maximum rating.

**Table 2-2 – HSSL Initial Baseline Design Principal Particulars and Machinery Characteristics**

| DIMENSIONS | | | MACHINERY | | |
|---|---|---|---|---|---|
| Length Overall | 560.0 | ft | Prop. Machinery Type | Gas Turbine | |
| Breadth Overall | 129.3 | ft | Number of Prop. Engines | 4 | |
| Depth to Wet Dk. (ABL) | 46.0 | ft | Prop. Engine Rating | 48,260 | hp |
| | | | Total Prop. Power | 193,040 | hp |
| Demihull Length | 560.0 | ft | | | |
| Demihull Breadth | 30.0 | ft | Propulsor Type | Waterjet | |
| Demihull Depth | 31.0 | ft | Waterjet Inlet Diameter | 7.4 | ft |
| Demihull Separation | 69.3 | ft | | | |
| | | | Lift Machinery Type | Diesel | |
| Strut Length | 542.8 | ft | Number of Lift Engines | 2 | |
| Strut Breadth (max) | 10.8 | ft | Lift Engine Rating | 2012 | hp |
| Strut Height | 15.0 | ft | Total Lift Power | 4024 | hp |
| | | | Number of Lift Fans | 2x2 | |
| | | | Lift Fan Diameter | 4.2 | ft |

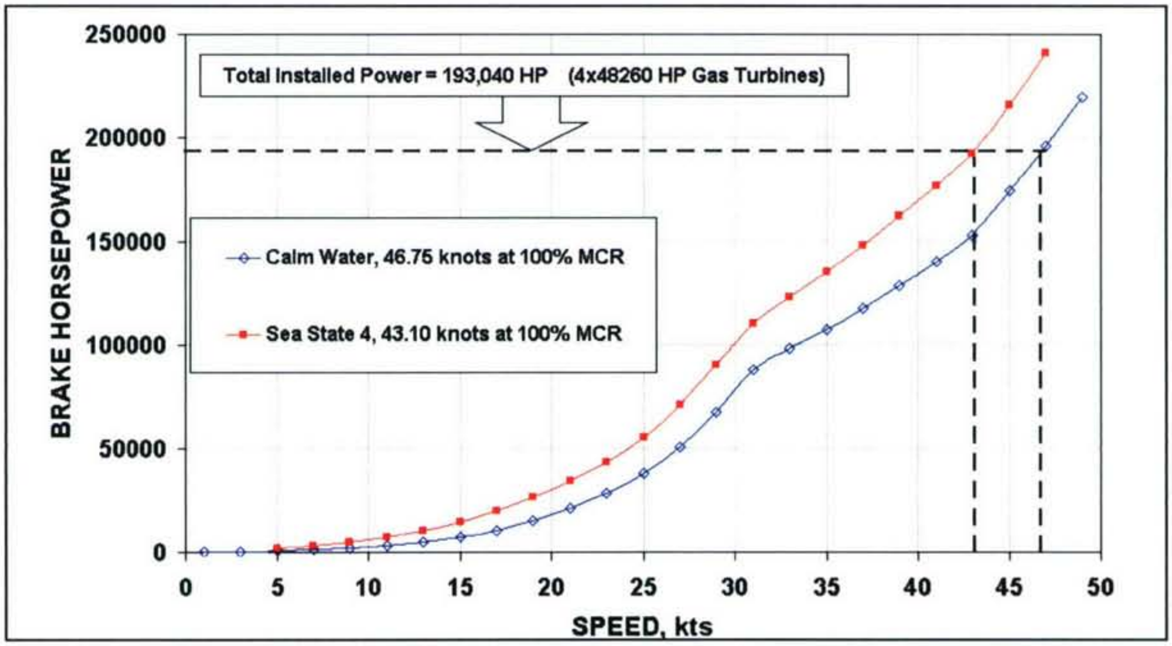


**Figure 2-5 – ComPASS™ Powering Estimate for HSSL Initial Baseline Design**

Based on the ComPASS™ generated hullform characteristics, which include basic dimensions, coefficients, and a simple prismatic representation of vessel geometry, faired lines and detailed geometry for the initial baseline HSSL design were developed offline utilizing the Non-Uniform Rational B-Splines (NURBS) modeling software Rhinoceros. The detailed geometry is required to support the panelization and grid generation required for the more advanced computational tools being evaluated during this effort.

The detailed hullform geometry is shown in Figure 2-6. The interior surfaces of the demihulls and struts are flat, flush surfaces to facilitate the creation of an effective seal when the retractable SES cushion seals are deployed. The 69.3 ft separation between the flush inboard faces of the demihulls results in a separation-to-length ratio (S/L = 0.124) which is lower than most smaller, conventional catamarans currently in operation; however, it should also be noted that in the current configuration the overall breadth of the vessel is nearly 130 ft. Although ONR indicated that larger breadths might be acceptable to the end-users of HSSL at the 22 November kick-off meeting, the issue of producibility must also be considered, as there are a limited number of facilities in the U.S. which can accommodate construction of a vessel exceeding this breadth.

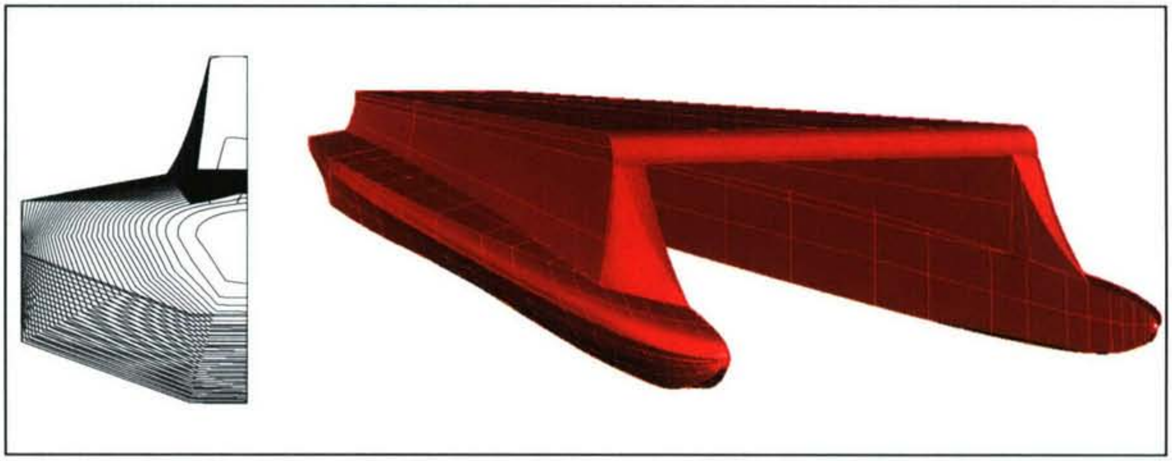

**Figure 2-6 – Initial HSSL Baseline Demihull Sections & Isometric Surface Representation**

Upon completion of the hullform definition, the geometry shown in Figure 2-6 was utilized in conjunction with the initial ComPASS™ output to generate loading condition details for each of the three operational modes inherent to the HSSL concept. These conditions are summarized in Table 2-3.

Additionally, notional longitudinal weight distributions were developed for each operational mode to support the calculation of seaway induced sectional loads. These weight distributions are shown graphically in Figure 2-7. Because the lift system in the SES mode is designed to be capable of achieving the 6.5 m shallow draft requirement from the full-load departure condition, loading details such as craft weight, centers of gravity, and mass distribution in the baseline SES mode are similar to those of the catamaran configuration. The weight distribution for the SWATH mode is also similar to that of the catamaran mode in all respects with the exception of the addition of 3542 LT of saltwater ballast. In all cases, development of the hullform and the weight distribution occurred simultaneously such that the LCG is designed to correspond to the Longitudinal Center of Buoyancy (LCB), resulting in a zero-trim operational condition.

**Table 2-3 – Summary of Initial HSSL Baseline Design Loading Condition Details**

| Parameter | Catamaran Mode | SWATH Mode | SES Mode |
|---|---|---|---|
| Total Craft Weight (LT) | 13,959 | 17,501 | 13,959 |
| Hydrostatic Displacement (LT) | 13,959 | 17,501 | 9,748 |
| Air Cushion Contribution (LT) | 0 | 0 | 4,211 |
| Design Draft (ft) | 26.9 | 37.0 | 21.3 |
| Wet Deck Clearance (ft) | 19.1 | 9.0 | 24.7 |
| LCG (Aft FP) | 328.18 | 326.29 | 328.18 |
| VCG (ABL) | 39.96 | 33.74 | 39.96 |
| Approx. Cushion Area ($ft^2$) | – | – | 35,343 |
| Cushion Pressure (psf) | – | – | 267 |
| Required Flow Rate, 5 kts (cfs) | – | – | 3,043 |
| Required Flow Rate, 10 kts (cfs) | – | – | 5,514 |
| Total Craft Weight (LT) | 13,959 | 17,501 | 13,959 |
| Hydrostatic Displacement (LT) | 13,959 | 17,501 | 9,748 |

As a final step in the definition of the initial HSSL baseline design, the preliminary waterjet performance predictions generated utilizing ComPASS™, which include data such as unit sizing, flow rates, velocities, efficiencies, etc., were supplemented with development of the detailed waterjet installation configuration. This was intended to support the accurate location of thrust vectors, inlet geometries, etc. as new and improved CDI waterjet performance prediction capabilities were implemented in the advanced computational tools as this effort progressed. The waterjet installation details are shown in Figure 2-8.

Note that the installation diameters associated with the waterjets are a primary driver in the sizing of the transom, and, in fact, a minor redesign of the HSSL stern or a custom fabricated flange is required in this case due to interference of the demihull shell plate and the outboard waterjet flange. It becomes clear from inspection of Figure 2-8 that a more "canoe-like" stern design may reduce drag substantially, but is not feasible in this particular case due to the need to accommodate very large waterjets in the transom. As noted previously, use of advanced axial-flow waterjet technology would mitigate this problem substantially; however, this technology has not yet progressed to the power levels required for the HSSL application.

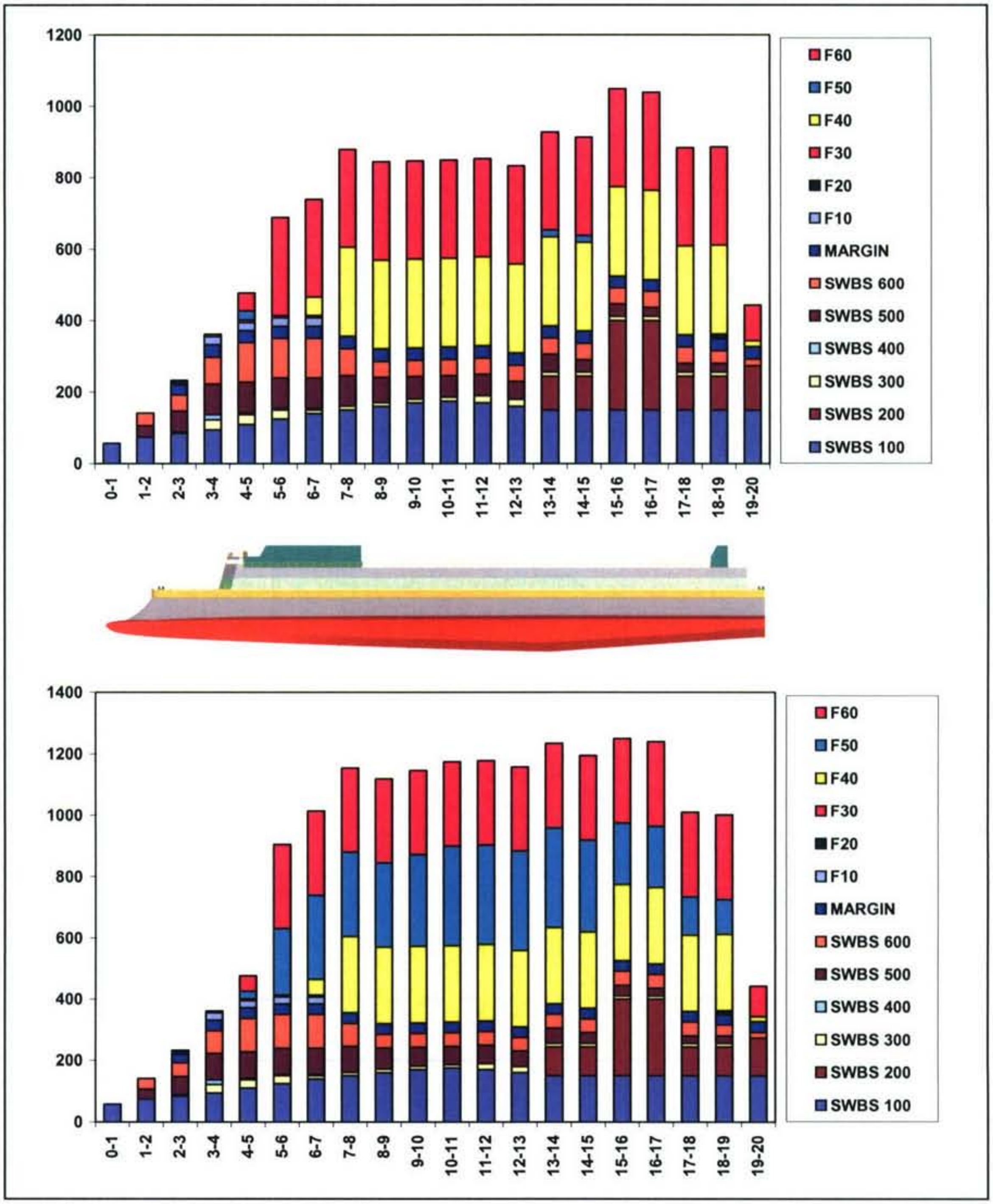


**Figure 2-7 – Longitudinal Weight Distribution of Initial HSSL Baseline Design in the Catamaran/SES Configuration (top) & the SWATH Configuration (bottom)**

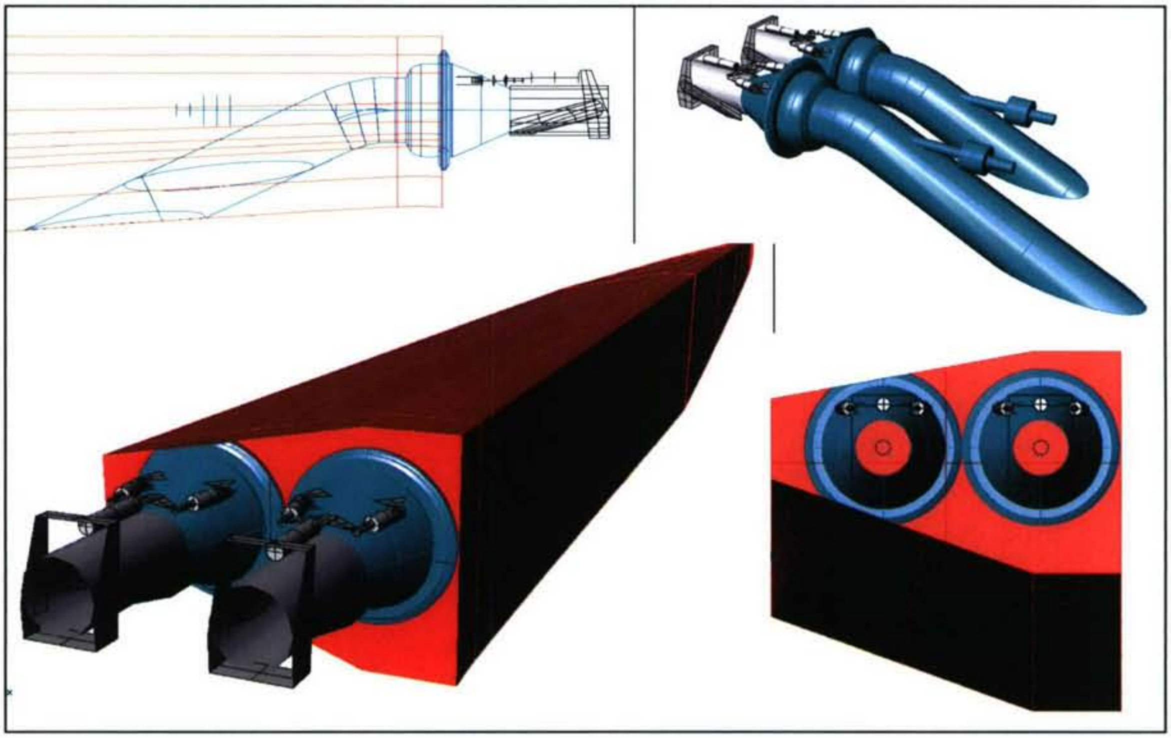

**Figure 2-8 – Waterjet Installation on Initial HSSL Baseline Design**

## 2.4 Revised Baseline Design

As the study progressed, the initial baseline design was evaluated in greater detail, and the results of preliminary analyses conducted with higher fidelity computational tools became available. From these investigations and data, it was apparent that (i) structural weight and (ii) resistance were under-predicted in the preliminary ComPASS™ design synthesis evolution. As a result, the HSSL baseline design was revisited to increase the structural weight margin from 10% in the initial baseline design to 26.5% in the revised baseline, and to increase the powering margin from 5% to 10%, respectively.

The ComPASS™ generated solution space for this revised baseline synthesis evolution is shown in Figure 2-9 along with the design point selected. This particular surface plot provides design data in four dimensions, as vessel displacement is given as a function of waterline length and demihull length-to-beam ratio by the elevation of the surface, while the color map provides life-cycle cost contours. As seen in Figure 2-9, displacement and life-cycle cost both tend to decrease as waterline length decreases and demihull L/B ratio increases (e.g. from left to right in the Figure). However, draft is also increasing in this direction, which creates a requirement for higher cushion pressures and correspondingly larger lift systems in order to achieve the target 6.5 meter draft in SES mode. As such, the design point selected lies towards the upper left-hand corner of the surface, where full-load draft is less than 30 ft and the corresponding cushion pressure requirements remain reasonable.

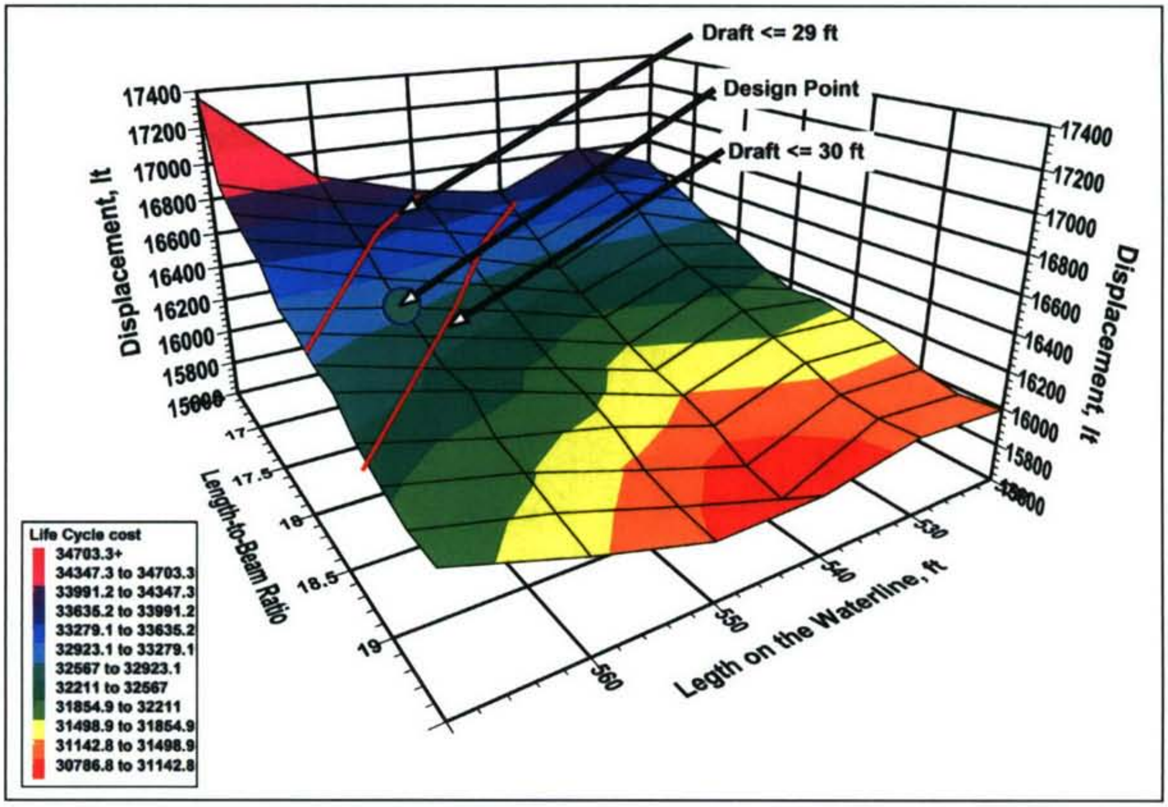


**Figure 2-9 – Solution Space for the Revised Baseline HSSL Design with Increased Structural Weight & Powering Margins**

Based on the design point selected, preliminary design data was generated utilizing ComPASS™, resulting in the basic characteristics shown in Table 2-4.

**Table 2-4 – Revised Baseline Design Principal Particulars and Machinery Characteristics**

| DIMENSIONS | | |
|---|---|---|
| Length Overall | 580.0 | ft |
| Breadth Overall | 134.1 | ft |
| Depth to Wet Dk. | 49.3 | ft |
| | | |
| Demihull Length | 580.0 | ft |
| Demihull Breadth | 31.5 | ft |
| Demihull Depth | 33.3 | ft |
| Demihull Separation | 71.0 | ft |
| | | |
| Strut Length | 559.9 | ft |
| Strut Breadth (avg.) | 10.0 | ft |
| Strut Height | 20.0 | ft |

| MACHINERY | |
|---|---|
| Prop. Machinery Type | Gas Turbine |
| Number of Prop. Engines | 4 |
| Prop. Engine Rating | 53,828 |
| Total Prop. Power | 215,312 |
| | |
| Propulsor Type | Waterjet |
| Waterjet Inlet Diameter | 8.2 |
| | |
| Lift Machinery Type | Diesel |
| Number of Lift Engines | 2 |
| Lift Engine Rating | 2797 |
| Total Lift Power | 5594 |
| Number of Lift Fans | 2x2 |
| Lift Fan Diameter | 6.1 |

Faired hull lines for the revised baseline HSSL design were again generated offline utilizing Rhinoceros, as shown in Figure 2-10. The overall geometry concept is generally similar to that of the initial baseline at the global level, expanded to reflect the modified

dimensions and volumetric distribution of the revised baseline design. Additional, localized refinements include (i) a reduction in the longitudinal stern rocker at the keel to increase the depth of the transom at the aft perpendicular, thereby improving the accommodation of the waterjet installation, (ii) reworking of the bottom plate planing surfaces, (iii) modification of the demihull shape in the forward sections of the craft, and (iii) modification of the forward portion of the struts and it's interface with the demihulls.

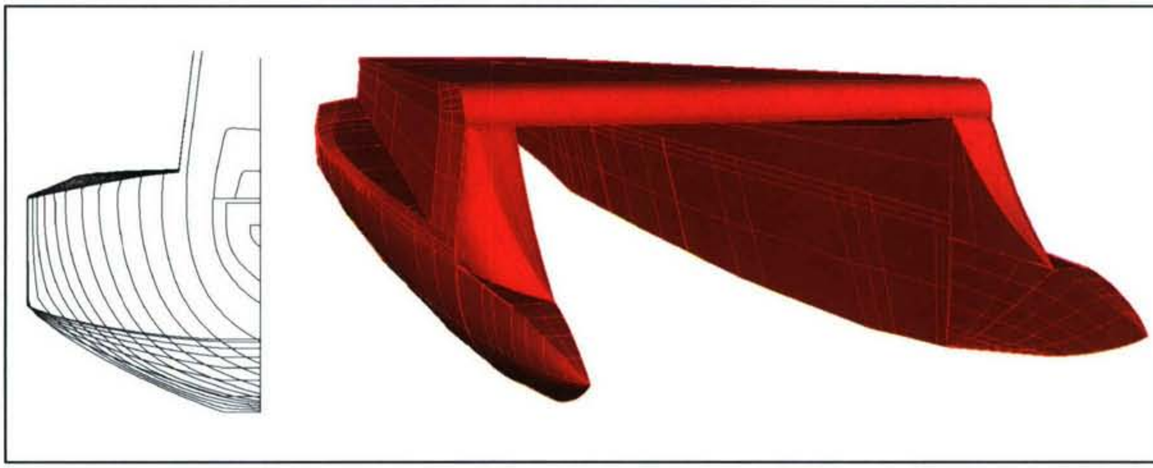

**Figure 2-10 – Revised Baseline Demihull Sections & Isometric Surface Representation**

Combining the ComPASS™ design data and the detailed hullform, loading condition details for the revised baseline design are as shown in Table 2-5. Table 2-6 goes on to provide a detailed comparison of the differences between the initial baseline and revised baseline for quick reference. Note in particular the substantial increases in structural weight and installed power, and the impact that these increases have on the fuel load required to achieve the 5000 nm range. Figure 2-11 illustrates the fact that the increased structural weight fraction inherent to the revised baseline design is more in line with the prevailing trends in SES design and construction.

At this stage of the design development, it was still believed that the ComPASS™ results for the revised baseline design remained optimistic, particularly in regard to resistance prediction. However, the results were deemed more reasonable than in the initial baseline. Although the majority of advanced computational analyses carried out at this stage were restricted to the initial baseline design due to time constraints, the revised baseline design provided a more valid, refined design point from which to begin the more detailed testing and evaluation process scheduled for the next phase of design.

**Table 2-5 – Summary of Revised Baseline Design Loading Condition Details**

| Parameter | Catamaran Mode | SWATH Mode | SES Mode |
|---|---|---|---|
| Total Craft Weight (LT) | 16,431 | 21,726 | 16,431 |
| Hydrostatic Displacement (LT) | 16,431 | 21,726 | 10,417 |
| Air Cushion Contribution (LT) | 0 | 0 | 6,014 |
| Design Draft (ft) | 28.7 | 40.3 | 21.3 |
| Wet Deck Clearance (ft) | 20.6 | 9.0 | 28.0 |
| LCG (Aft FP) | 345.87 | 339.80 | 345.87 |
| VCG (ABL) | 40.41 | 32.95 | 40.41 |
| Approx. Cushion Area ($ft^2$) | – | – | 37,630 |
| Cushion Pressure (psf) | – | – | 358 |
| Required Flow Rate, 5 kts (cfs) | – | – | 3590 |
| Required Flow Rate, 10 kts (cfs) | – | – | 6446 |

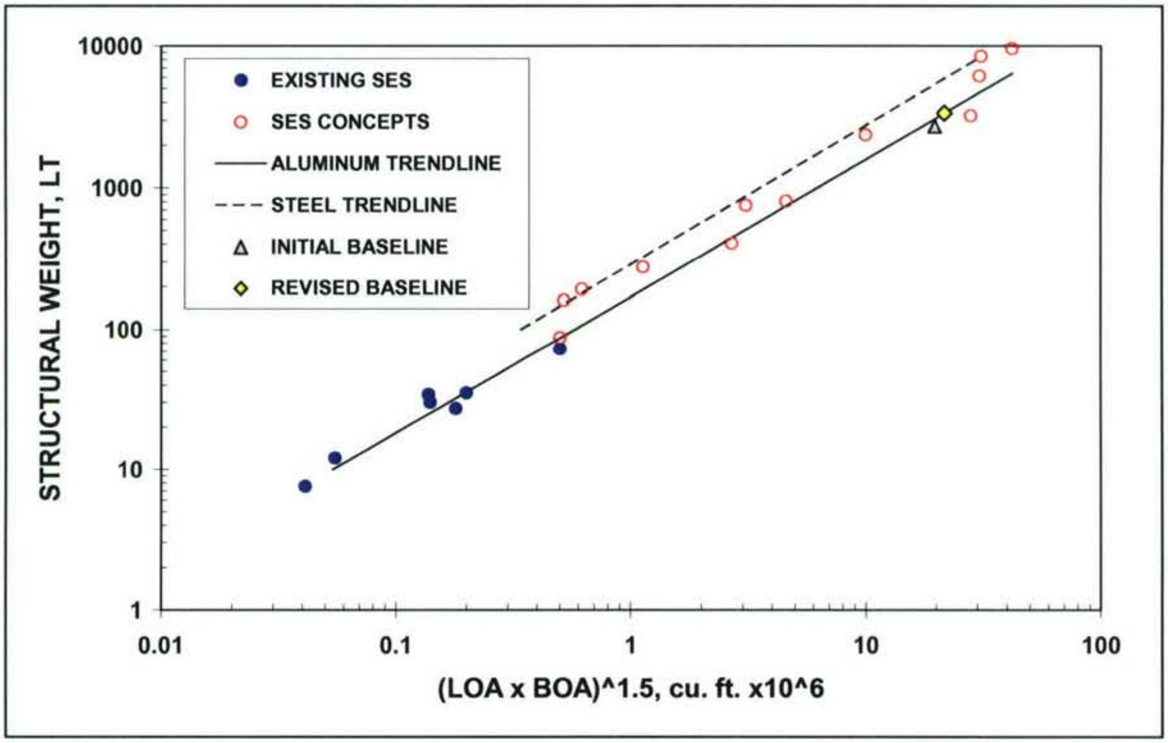


**Figure 2-11 – Comparison of HSSL Structural Weight Estimates Against Existing SES Designs**

**Table 2-6 – Comparison of Initial and Revised Baseline Design Characteristics**

| Parameter | Initial Baseline | Revised Baseline |
|---|---|---|
| **Displacement (LT)** | **13,959** | **16,431** |
| Length Overall (ft) | 560 | 580 |
| Beam Overall (ft) | 129.3 | 134.1 |
| Draft, Catamaran Mode (ft) | 26.9 | 29.4 |
| Draft, SWATH Mode (ft) | 37.0 | 40.3 |
| Draft, SES Mode (ft) | 21.3 | 21.3 |
| **Total Installed Power (hp)** | **193,040** | **215,312** |
| Transport Efficiency, WV/P | 21.4 | 22.6 |
| Structure Weight, SWBS 100 (LT) | 2,723 | 3,360 |
| Propulsion Weight, SWBS 200 (LT) | 1,002 | 1,298 |
| Electrical Weight, SWBS 300 (LT) | 246 | 463 |
| Command & Control Weight, SWBS 400 (LT) | 30 | 30 |
| Auxiliaries Weight, SWBS 500 (LT) | 1,012 | 1,109 |
| Outfitting Weight, SWBS 600 (LT) | 1,064 | 1,114 |
| Weight Margin (LT) | 608 | 737 |
| **LIGHTSHIP WEIGHT (LT)** | **6,685** | **8,111** |
| Fuel Load (LT) | 3,035 | 4,070 |
| Payload (LT) | 4,000 | 4,000 |
| Other Loads (LT) | 239 | 250 |
| **TOTAL DISPOSABLE LOAD (LT)** | **7,274** | **8,320** |

## 2.5 Steel Variant

The baseline HSSL design described above (both the initial and revised variants) is intended to be of all aluminum construction, and, if ultimately produced, would represent the largest aluminum ship built to date. Currently, that distinction belongs to the Techno-Superliner (TSL), which is a 460 ft, 4000+ LT all aluminum SES using the largest waterjets built to date and is capable of speeds in excess of 40 knots. Although the historical precedents governing the state-of-the-art in aluminum construction are rapidly expanding, as evidenced by vessels such as the TSL shown in Figure 2-12, the use of all aluminum construction for vessels such as HSSL is still viewed as a significant risk item by many throughout the naval design community. In fact, during the initial kick-off meeting for this program, ONR expressed these concerns directly.

**Figure 2-12 – Techno-Superliner: a 460 ft All-Aluminum SES Capable of 40+ Knots**

In response to this discussion, CDIM-SDD was tasked to perform a parallel design synthesis evolution in ComPASS™, exploring the impacts of utilizing steel hull construction for the HSSL application, subject to the same performance targets specified in Table 2-1 of this document. The solution space for this evolution is shown in Figure 2-13, with full-load displacement in the catamaran mode again represented by the elevation of the surface, and life-cycle cost represented by the color map.

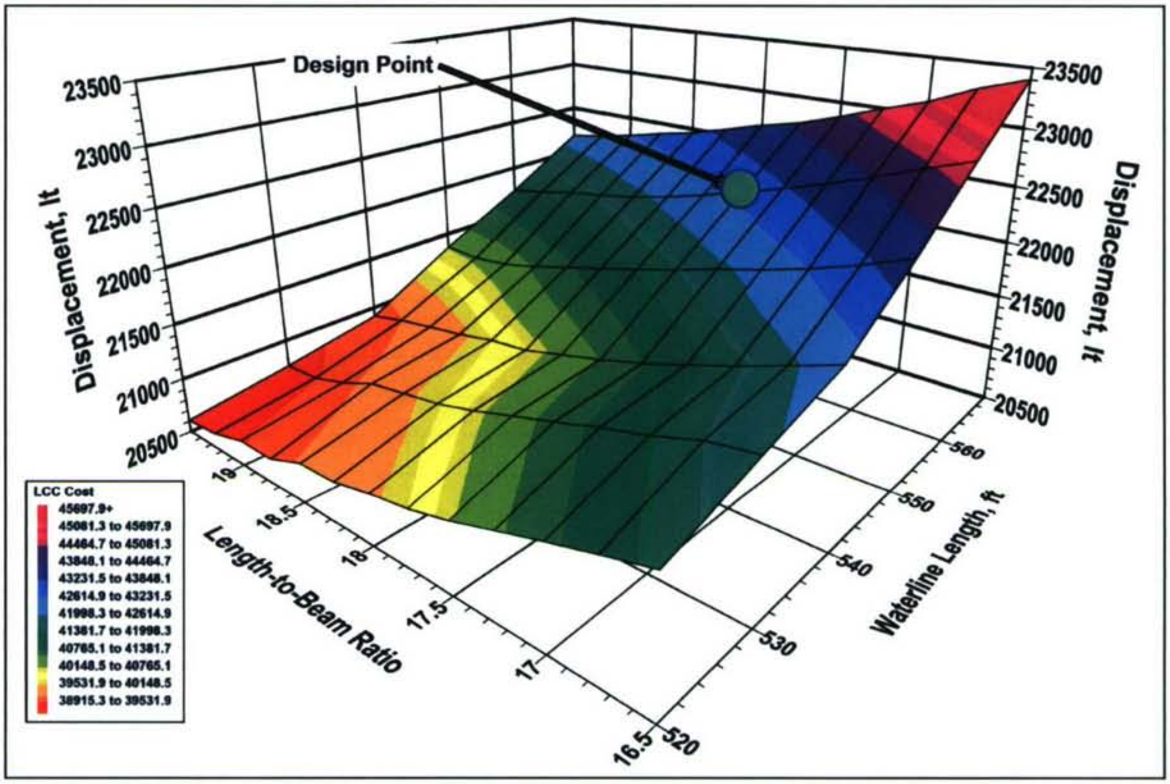


**Figure 2-13 – Solution Space for the Higher-Strength Steel HSSL Design Variant**

For this evaluation, higher strength AH40 steel, with a minimum yield strength of approximately 56 ksi, was assumed. The characteristics of the steel design point selected are shown in comparison to the revised aluminum baseline HSSL in Table 2-7. The structural weight for the steel variant is more than double the weight of the revised aluminum configuration, which consequently impacts the powering requirements and spirals through the entire design in terms of increased power plant weight, fuel loads, etc. The net result is a 35.5% increase in full-load displacement for a platform of generally consistent dimensions with steel construction.

**Table 2-7 – Comparison of the Revised Aluminum Baseline Design & a High-Strength Steel Variant**

| Parameter | Revised Aluminum Baseline | High-Strength Steel Variant |
|---|---|---|
| **Displacement (LT)** | **16,431** | **22,262** |
| Length Overall (ft) | 580 | 580 |
| Beam Overall (ft) | 134.1 | 134.1 |
| Draft, Catamaran Mode (ft) | 29.4 | 39.8 |
| Draft, SWATH Mode (ft) | 40.3 | 49.9 |
| Draft, SES Mode (ft) | 21.3 | 21.3 |
| Cushion Pressure, SES Mode (psf) | 360 | 700+ |
| **Total Installed Power (hp)** | **215,312** | **257,160** |
| Transport Efficiency, WV/P | 22.6 | 25.6 |
| Structure Weight, SWBS 100 (LT) | 3,360 | 7,188 |
| Propulsion Weight, SWBS 200 (LT) | 1,298 | 1,710 |
| Electrical Weight, SWBS 300 (LT) | 463 | 561 |
| Command & Control Weight, SWBS 400 (LT) | 30 | 30 |
| Auxiliaries Weight, SWBS 500 (LT) | 1,109 | 1,285 |
| Outfitting Weight, SWBS 600 (LT) | 1,114 | 1,178 |
| Weight Margin (LT) | 737 | 1195 |
| **LIGHTSHIP WEIGHT (LT)** | **8,111** | **13,146** |
| Fuel Load (LT) | 4,070 | 4,857 |
| Payload (LT) | 4,000 | 4,000 |
| Other Loads (LT) | 250 | 259 |
| **TOTAL DISPOSABLE LOAD (LT)** | **8,320** | **9,116** |

The substantial increase in displacement has its largest impact on the operational draft of the vessel, which is nearly 40 ft in the basic catamaran mode of operation for the higher strength steel design variant. This presents a serious design issue for the HSSL application because of the critical nature of the requirement to service austere ports and operate at shallow drafts. In this case, it is anticipated that the cushion pressure in the SES mode would be in excess of 700 psf in order to achieve the stated HSSL shallow draft requirement of 6.5m. Figure 2-14 illustrates quite clearly that this results in a cushion pressure-to-length ratio that is far in excess of the prevailing trend in SES design and construction. Although it would not necessarily be impossible to satisfy the draft requirement with a steel hull with SES air cushion assist, the utilization of steel hull construction for a HSSL design subject to the highly demanding performance requirements of Table 2-1 is, at this time, considered to be too high of a risk.

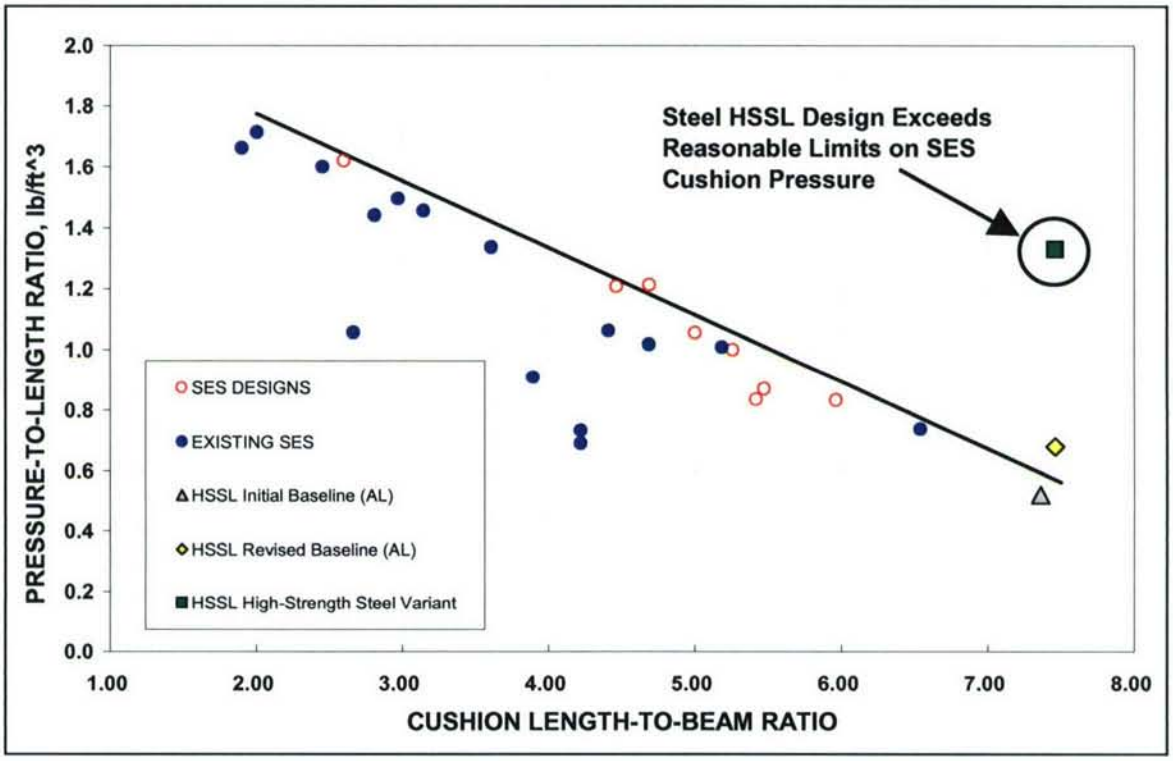


**Figure 2-14 – Prevailing Trend of Cushion Pressure-to-Length Ratio in SES Design**

## 2.6 Variations in Waterplane Area

As noted previously, in order to exercise the advanced computational tools in their current form, it was necessary to proceed with a point design.. However, due to ONR's emphasis on the parametric nature of the HSSL program at large, CDIM-SDD was also tasked to develop a "family of designs" with varying degrees of "SWATHness" in order to assess the ability of the advanced tools to capture the impact of strut width and the associated variations in waterplane area on critical performance related quantities such as seaway induced motions and loads.

Preliminary assessments indicated that key overall or "whole-ship" design parameters such as full-load displacement were not overly sensitive to small variations in strut width, and therefore a similar demihull geometry was maintained throughout the development of the "family of ships". Only strut design was variable.

The range of variation in strut width was established based on an investigation of the natural periods in roll, pitch, and heave for the HSSL design when operating in SWATH mode. In order to avoid the potential for resonant conditions when the various motion components are coupled, the available range of strut widths was restricted to a relatively narrow band from approximately 8 ft to 12 ft in width, as shown in Figure 2-15. Considering that the revised aluminum baseline design described above was developed around an average strut width of 10 ft, the natural progression to the "family of designs" concept involved the generation of two additional strut configurations, one "narrow"

variant at an average width of 8 ft, and one "wide" variant at an average width of 12 ft. The resultant "family of designs" is shown graphically in Figure 2-16.

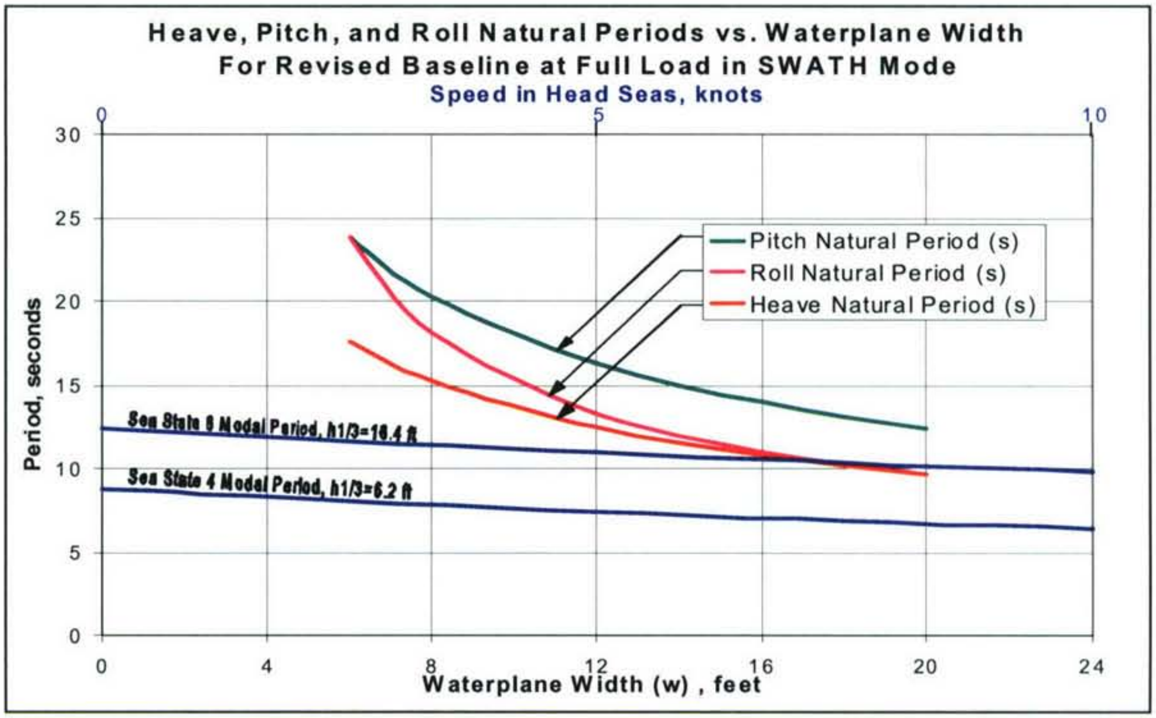


**Figure 2-15 – Detuning Natural Periods in Roll, Pitch, & Heave for Operation in SWATH Mode**

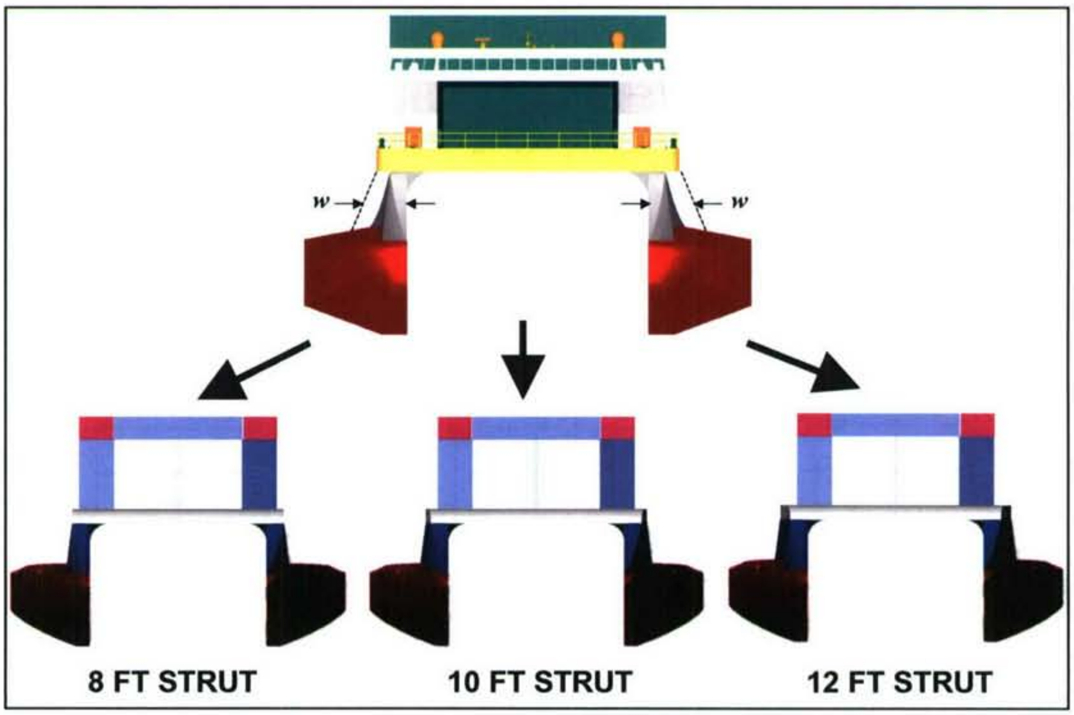


**Figure 2-16 – Family of HSSL Designs of Varying "SWATHness"**

Due to constraints on time and budget, only limited advanced computational analyses were carried out on the full "family of designs". These analyses performed by SAIC focused solely on seakeeping evaluations with Veres and Lamp at this stage.

## 2.7 Summary of Concept Designs

The HSSL program presents a very demanding set of desired capabilities to the designer, as the overall concept proposed must: (i) be capable of efficiently transporting very large payloads (4000 tons) at high speeds (greater than 40 knots) over long distances (greater than 5000 n.miles); (ii) have shallow draft to permit access to as many foreign ports as possible; (iii) have low pitch, heave and roll motions in response to seaway conditions; and (iv) require reliable low-risk technologies that can result in a viable near-term affordable solution.

To achieve this capability, a multihull is probably best suited to solve problems (i) and (iv), an SES best for problem (ii), and a SWATH for problem (iii). However, no ship is best for all unless a viable hybrid of all three can be conceived. Thus, the concept proposed herein looks at combining all three and, at first examination, it would appear that there is a significant opportunity for the attributes of each concept to synergistically work together to produce a vessel that is operationally transformable to be far superior for each element of the mission than any of the three original concepts alone.

The concept put forth is a vessel that can easily transform itself to operate either as a Catamaran, a SWATH, or an SES. The Catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability, and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping, and the SES because of its ability to afford shallow draft with end seals deployed, and to combine with the SWATH to enhance seakeeping at low speed.

In addition to representing an innovative "answer" to the highly demanding set of desirable capabilities envisioned for the HSSL design, the hybrid Catamaran / SWATH / SES concept offers several pertinent challenges to the advanced computational tools at the heart of the Subtopic B effort. First of all, the multi-modal nature of the concept challenges the scope of the tool's hydrodynamic prediction capabilities against a wide range of operational concepts (traditional high-speed catamaran, air-supported ship, etc.). Secondly, specific geometrical features of the hullform proposed present additional computational challenges, such as the proximity of the top of the demihull to the free surface in catamaran mode, which (i) stresses the ability of the tools to accurately predict wetted surface and wave drag in calm water, and (ii) which results in rapid variations in waterplane area during seaway operations, challenging predictions of seakeeping performance and dynamic loads.

# 3 Concept Design Refinement

## 3.1 Desired Capabilities

The desired capabilities, as set forth in the ONR BAA, defined a set of design parameters with an associated target value as shown previously in Table 2-1 and repeated below as Table 3-1. These were used to frame the design space and, as such, served as inputs to the ComPASS™ synthesis and sizing program in order to determine a balanced design.

**Table 3-1 – ONR HSSL Desired Capabilities**

| Parameter | Numerical Value | Type |
|---|---|---|
| Displacement | $\leq$ 12,000 tons | Soft |
| Length | $\approx$ 560 feet | Soft |
| Payload | $\approx$ 4,000 tons | Hard |
| Sustained Transit Speed | $\geq$ 43 knots | Hard |
| Unrefueled Range at Transit Speed | $\geq$ 5,000 nautical miles | Hard |
| Draft at Port Entry | $\leq$ 6.5 meters | Hard |
| Special Capability – Load Transfer | Drive vehicles from ship-to-ship | Hard |
| Special Capability – Air Capable | Undefined capability | Soft |
| Full Performance Weather Limit | $\geq$ Sea State 4 | Hard |

## 3.2 Design Activities

The design activities followed a traditional ship design spiral, tailored to the actual project as shown in Figure 3-1.

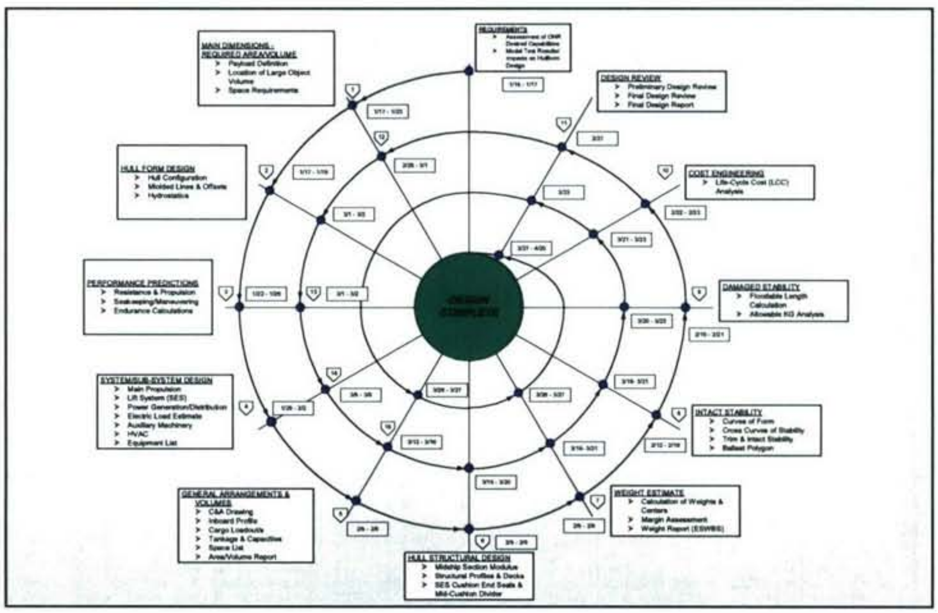

**Figure 3-1 – ONR HSSL LDS-HSC Ship Design Spiral**

The activities shown in the design spiral included the following elements:

1. **MAIN DIMENSIONS - REQUIRED AREA/VOLUME**
   a. Payload Definition
   b. Location of Large Object Volume
   c. Space Requirements.
2. **HULLFORM DESIGN**
   a. Hull Configuration
   b. Molded Lines & Offsets
   c. Hydrostatics
3. **PERFORMANCE PREDICTIONS**
   a. Resistance & Propulsion
   b. Seakeeping/Maneuvering
   c. Endurance Calculations
4. **SYSTEM/SUB-SYSTEM DESIGN**
   a. Main Propulsion
   b. Lift System (SES)
   c. Power Generation/Distribution
   d. Electric Load Estimate
   e. Auxiliary Machinery
   f. HVAC
   g. Equipment List
5. **GENERAL ARRANGEMENTS & VOLUMES**
   a. C&A Drawing
   b. Inboard Profile
   c. Cargo Loadout/s
   d. Tankage & Capacities
   e. Space List
   f. Area/Volume Report
6. **HULL STRUCTURAL DESIGN**
   a. Midship Section Modulus
   b. Structural Profiles & Decks
   c. SES Cushion End Seals & Cushion Divider
7. **WEIGHT ESTIMATE**
   a. Calculation of Weights & Centers
   b. Margin Assessment
   c. Weight Report (ESWBS)
8. **INTACT STABILITY**
   a. Curves of Form
   b. Cross Curves of Stability
   c. Trim & Intact Stability
   d. Ballast Polygon

**9. DAMAGED STABILITY**

a. Floodable Length Calculation
b. Allowable KG Analysis

**10. COST ENGINEERING**

a. Life-Cycle Cost (LCC) Analysis

Each of these elements is discussed in some detail in the following sections of this report.

## 3.3 Payload Definition

As can be seen from Table 3-1, the desired Payload capability of the vessel is set at approximately 4000 S.tons of cargo. From research into Sea Power 21 related documentation, it was determined that this value represents the lift requirements of the U.S. Army's Future Force, specifically as called out in a report issued by the Defense Science Board (DSB) Task Force on Mobility and shown in Table 3-2, which is built in large part around the Army's Future Combat System (FCS).

**Table 3-2 – Defined Payload Requirements**

| BCT Type | Personnel | | Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Vehicles | | Weight (S.tons) | | Area (kilo $ft^2$) | |
| | BnTF | BCT/UA | BnTF | BCT/UA | BnTF | BCT/UA | BnTF | BCT/UA |
| FCS | 860 | 2,600 | 300 | 860 | 3,600 | 10,000 | 50 | 140 |
| Stryker | 1,100 | 3,900 | 390 | 1,070 | 4,000 | 15,000 | 71 | 300 |
| Heavy | 900 | 3,700 | 390 | 1,700 | 6,000 | 22,500 | 77 | 320 |
| Light | 950 | 3,400 | 380 | 1,350 | 1,800 | 7,400 | 44 | 180 |
| FCS = Future Combat System (estimate) | | | | | BnTF = Battalion Task Force | | | |
| BCT/UA = Brigade Combat Team/Unit of Action | | | | | | | | |

Furthermore, as indicated by the heavy lined boxes in Table 3-2, it can be deduced that the 4000 S.ton capability represents a division of the Stryker Brigade Combat Team (BCT/UA), in particular a Stryker Battalion Task Force (BnTF). Although the associated area of 71,000 $Ft^2$ called out in the above table was useful to help determine the initial sizing of the ship's large object volumes, a more detailed description of the Stryker BnTF payload was needed in order to be able to define specific area/volume requirements needed in order to develop the payload arrangements. This detail was found in an Army presentation entitled "The Army Modular Force" that clearly breaks down the Stryker BCT into its component parts, as illustrated in Figure 3-2 and Figure 3-3 which are taken from that presentation.

This information in-turn enabled the creation of the detailed payload definition shown in Table 3-3, and the allocation of sufficient deck area and deck clear height, thereby allowing for the arrangement of the individual cargo inventory while also reflecting the appropriate vehicle flow paths and turning radius' for proper maneuvering. Together with the other large object volume spaces, including the propulsion system, the power generation and distribution system, and the tankage, this information drove the

development of the general arrangements of the vessel. The detailed Payload Arrangements, with geometrically accurate models of the individual vehicles, are illustrated in Figure A-18 and Figure A-19 of Appendix A-3.

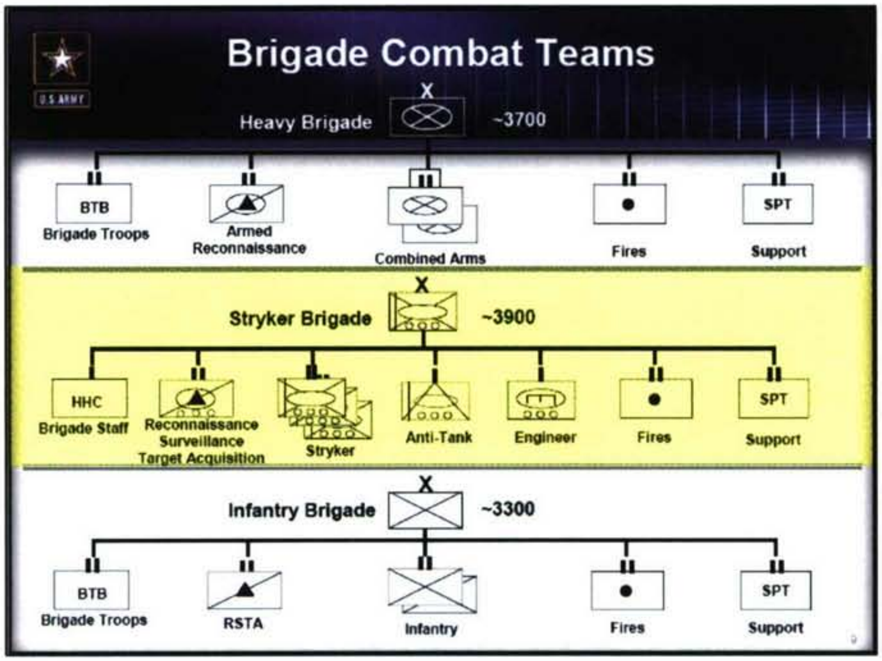


Figure 3-2 – U.S. Army Brigade Combat Teams

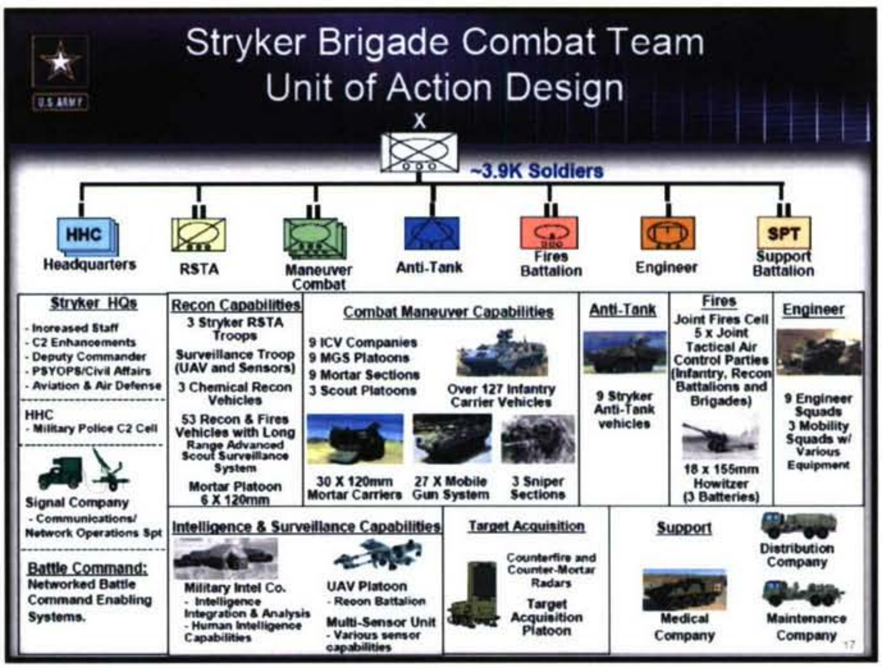


Figure 3-3 – Stryker Brigade Combat Team Details

## Table 3-3 – Detailed Payload Definition for HSSL LDS-HSC

| HSSL LDS-HSC: | PAYLOAD DEFINITION | | | Quantity | | Weight | | | | Dimensions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | BCT IIA | BnTF | Unit Weight | | BCT IIA | BnTF | Length | Width | Height |
| Capabilities | Vehicle Description | Vehicle Designation | Vehicle Picture/s | 5 Div | 5 Div | lbs | stons | stons | stons | inches | inches | inches |
| RECON | | | | | | | | | | | | |
| | NBC Reconnaissance Vehicle | M1135 NBCRV | NBC Reconnaissance  http://www.globalsecurity.org/military/systems/ground/iav-pics-nbc.htm | 3 | 3 | 38000 | 19 | 57 | 57 | 275 | 107 | 104 |
| | Reconnaissance Vehicle | M1127 RV | Reconnaissance Vehicle  http://www.globalsecurity.org/military/systems/ground/iav-pics-rv.htm | 53 | 30 | 38000 | 19 | 1007 | 570 | 275 | 107 | 104 |
| | Mortar Carriers | M1129 MC | Mortar Carrier  | 6 | 4 | 38000 | 19 | 114 | 76 | 275 | 107 | 104 |
| COMBAT MANUEVER | | | | | | | | | | | | |
| | Infantry Carrier Vehicle | M1126 ICV | Infantry Carrier Vehicle  http://www.globalsecurity.org/military/systems/ground/iav-pics-icv.htm | 127 | 70 | 38000 | 19 | 2413 | 1330 | 275 | 107 | 104 |
| | Mortar Carrier | M1129 MC | Mortar Carrier  | 30 | 15 | 38000 | 19 | 570 | 285 | 275 | 107 | 104 |
| | Mobile Gun System | M1128 MGS | Mobile Gun System  http://www.globalsecurity.org/military/systems/ground/iav-pics-mgs.htm | 27 | 15 | 41000 | 20.5 | 553.5 | 307.5 | 275 | 107 | 104 |
| ANTI-TANK | | | | | | | | | | | | |
| | Anti Tank Guided Missile | M1134 ATGM | Anti-tank Guided Missile  http://www.globalsecurity.org/military/systems/ground/iav-pics-atgm.htm | 9 | 5 | 38000 | 19 | 171 | 95 | 275 | 107 | 104 |
| FIRES | | | | | | | | | | | | |
| | Fire Support Vehicle | M1131 FSV | Fire Support Vehicle  http://www.globalsecurity.org/military/systems/ground/iav-pics-fsv.htm | 5 | 3 | 38000 | 19 | 95 | 57 | 275 | 107 | 104 |
| | 155mm Howitzer | M198 HMT |  http://www.army.mil/cmh/books/www/258b.htm | 54 | 30 | 15800 | 7.9 | 426.6 | 237 | 488.4 | 110.4 | 114 |
| ENGINEER | | | | | | | | | | | | |
| | Engineer Support Vehicle | M1132 ESV | Engineer Squad Vehicle  http://www.globalsecurity.org/military/systems/ground/iav-pics-esv.htm | 9 | 5 | 38000 | 19 | 171 | 95 | 275 | 107 | 104 |
| SUPPORT | | | | | | | | | | | | |
| | Medical Evacuation Vehicle | M1133 MEV | Medical Evacuation  http://www.globalsecurity.org/military/systems/ground/iav-pics-mev.htm | 9 | 5 | 38000 | 19 | 171 | 95 | 275 | 107 | 104 |
| | Mobility Squad Support Vehicle | M998 Cargo/Troop Carrier<br>M1038 Cargo/Troop Carrier, w/winch<br>M1043 Armament Carrier<br>M1044 Armament Carrier, w/winch<br>M1045 TOW Carrier<br>M1046 TOW Carrier, w/winch<br>M997 Ambulance, basic armor<br>M1037 Shelter Carrier<br>M1042 Shelter Carrier, w/winch<br>M1097 Heavy HMMWV (payload of 4,400 pounds) |  http://www.army.mil/cmh/books/www/267.htm<br>http://www.army.mil/fact_files_site/hmmwv/index.html | 268 | 67 | 5900 | 2.95 | 790.6 | 197.65 | 180 | 85.2 | 54 - 72 |
| | Mobility Squad Support Vehicle | M998 Cargo/Troop Carrier<br>M1038 Cargo/Troop Carrier, w/winch<br>M1043 Armament Carrier<br>M1044 Armament Carrier, w/winch<br>M1045 TOW Carrier<br>M1046 TOW Carrier, w/winch<br>M997 Ambulance, basic armor<br>M1037 Shelter Carrier<br>M1042 Shelter Carrier, w/winch<br>M1097 Heavy HMMWV (payload of 4,400 pounds) |  http://www.globalsecurity.org/military/systems/ground/m1097.htm | 192 | 48 | 7600 | 3.8 | 729.6 | 182.4 | | | |
| | Trailer Tank Water | M149A2 |  | 50 | 25 | | 1.5 | 75 | 37.5 | 162 | 81 | 81 |
| | High Mobility 1 1/4 Ton Cargo Trailer | M1102 |  | 50 | 25 | | 0.7 | 35 | 17.5 | 136 | 86 | 100 |
| | High Mobility 3/4 Ton Cargo Trailer | M1101 |  | 50 | 25 | | 0.7 | 35 | 17.5 | 136 | 86 | 100 |
| | Distribution Company | M1083 MTV |  http://www.globalsecurity.org/military/systems/ground/m1083.htm | 9 | 5 | 22480 | 11.24 | 101.16 | 56.2 | 273 | 96 | 112 |
| | Distribution Company | M977, M978<br>M983, M984, & M985 |  http://www.army.mil/cmh/books/www/265.htm<br>http://www.army.mil/fact_files_site/hemtt/index.html | 9 | 5 | 62000 | 31 | 279 | 155 | See Data at indicated hyperlinks | See Data at indicated hyperlinks | See Data at indicated hyperlinks |
| | Maintenance Company | M911<br>M746, M747 |  http://www.army.mil/fact_files_site/het/index.html | 9 | 5 | 52600 | 26.3 | 236.7 | 131.5 | See Data at indicated hyperlinks | See Data at indicated hyperlinks | See Data at indicated hyperlinks |
| | | | TOTALS FOR STRYKER BATTALION TASK FORCE (BnTF): | | 390 | | | | 4000 | | | |

## 3.4 Concept Design

This task was aimed at refining the ship's overall dimensions, mass properties, general characteristics and developing the ship's compartmentation, topside design, external arrangements, and general access throughout the ship. The compartment areas, volume, tankage, and stations necessary to support the ship mission were also developed. Weight, area and volume margins were then documented and also used during the ship design development. The general arrangements, including an outboard profile, an inboard profile, and topside arrangements were also developed.

### 3.4.1 Overall Design Optimization & Trade-Offs

The following discussion identifies the approach and trade-offs taken to establish the ship's overall dimensions, mass properties and general characteristics that are necessary in order to satisfy the overall ship mission-desirable characteristics at minimum cost. Note that the process also included the conduct of model tests funded by a separate but parallel ONR program (Reference 2) at DTMB Carderock, so an initial design needed to be specified from which a model could be designed. The process to develop this initial design is described below, followed by the update that took place with input from the model tests.

It was the goal here to design a ship that could satisfy all of the desired HSSL mission capabilities identified in Table 3-1. To accomplish this, we used the CDIM-SDD Whole-Ship Design Synthesis Model, ComPASS™, which we have been using and continuously developing for more than 29 years.

ComPASS™ is designed to rapidly automate the traditional ship-design spiral and, via numerous iterations, can converge on balanced solutions within seconds. The software is coded in C++, has an object-oriented architecture, and runs within a Windows environment on a standard PC. The impact of varying over 400 inputs can be examined, usually one at a time. Inputs include requirements described within a comprehensive 8-segment characterization of a mission or route, and include ship geometry, design margins and standards, etc.

For each individual segment of the mission or route, the ship's speed, wave height, sea spectra, seaway modal period, ambient air temperature and percent of the time spent in the segment can be specified to create a complete mission or route profile. All can then be varied to determine the overall impact on cost, for example. Systems weights and volumes are calculated and the ship's center of gravity (CG) location determined for the continuous assessment of ship stability.

With support from the Office of Naval Research (ONR) and technical oversight by Naval Surface Warfare Center, Carderock Division (NSWCCD) and Naval Sea Systems Command (NAVSEA), the software has been developed with a strong focus on the use of physics-based algorithms. Not all relationships in the process of ship design can be

easily made to be physics-based, but the emphasis on physics has been achieved in ComPASS™ to help ensure that extrapolations to new "out-of-the-box" designs can be accomplished with a higher degree of confidence than could be expected with more traditional methods that rely heavily on both empirical and historical trends. The software has been extensively Beta tested and used to support many high-profile, foreign and domestic, warship and commercial ship programs, including ships that have been built and others that are currently under study or in detail design. Since 1978, the tool has been used to support over 50 separate design projects. The current version has an enhanced graphics ship visualization package and can generate the specific inputs that are necessary to run the U.S. Navy's standard design tool ASSET.

Predicted total cost is not precise, but typically within about 15% (or much better with calibrated predictions). With this accuracy, ComPASS™ has already helped numerous acquisition programs establish balanced and affordable requirements and the designers select affordable technologies. With the recent huge advances in desktop computing capability, ComPASS™ is able to rapidly explore the solution space for a multitude of design options to assist the customer in arriving at a set of parameters representing the most cost-effective variant.

Figure 3-4 shows, for the HSSL RO/RO ship, a 4-dimensional surface contour plot of ship life-cycle cost and displacement versus ship dimensions (L & L/B) generated by ComPASS™ using the desired capabilities of Table 3-1 and the ship operating as a catamaran at high speed. The ordinate on the chart is ship full-load displacement and the colors show bands of varying life-cycle cost according to the inset legend.

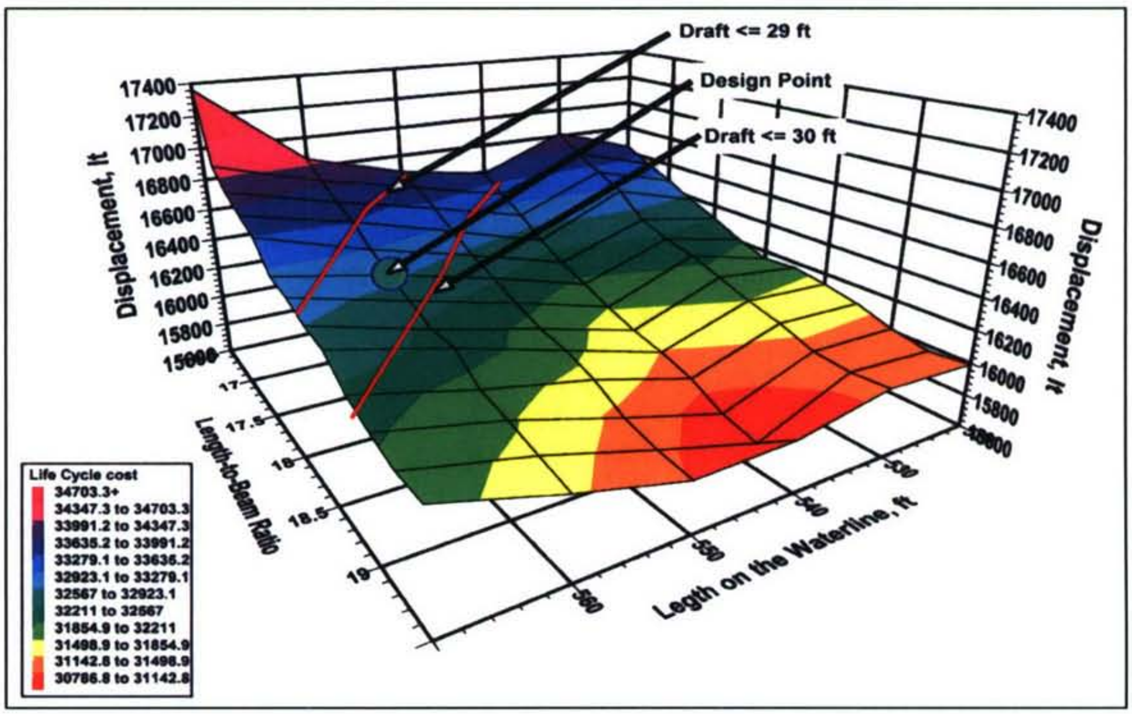


**Figure 3-4 – HSSL Ship Displacement and Life-Cycle Cost vs. Ship L/B and L**

Every point on the surface of Figure 3-4 identifies a balanced HSSL design that will meet the desired capabilities of Table 3-1, including speed, range, payload, and margins etc., but not draft. To meet the draft requirement of 6.5m (21.33 ft) or less, it was necessary to use the SES cushion. With the cushion, it was estimated that the ship's draft could be reduced by 8.17 ft. Thus, the maximum draft without the cushion operating could not exceed (21.33 ft + 8.17 ft), or 29.5 ft. This limit is indicated on Figure 3-4 by the lines labeled 29 ft and 30 ft, and the least cost solution is identified by the point at a demihull L/B of 18 and a demihull waterline length of 560 ft. However, the HSSL model tests conducted in December 2006 showed that the cushion system could change the ship's draft by more than 8.17 ft full-scale, thus the value of 8.17 ft is considered conservative. In other words, any further exploration of the design should take advantage of being able to accept an unassisted draft greater than 30 ft, resulting in a lowering of the ship's overall life-cycle cost.

The principal characteristics of the design chosen at this initial stage (prior to the model tests) are shown in column 1 in Table 3-4 as the Baseline Configuration Rev. 0. The next stage in the optimization process was to examine various power plant options including an update of the drag prediction based on the model test results. When using ComPASS™ during the feasibility stage of a design, it is fairly typical for the user to set the power plant flag to either "Rubber" or to "Step Increment". The "Rubber" command allows the plant to grow and shrink in accordance with the overall design, but without reference to a "real" prime mover. The "Step Increment" command, on the other hand, steps through a database of different real engine options, stepping up or down to match the next higher or lower power level associated with the specific engine. When the design transitions into the concept phase, it is often the case that the naval architect will choose to define a specific power plant and therefore the "User Defined" command is chosen. For the HSSL LDS-HSC, the power plant configurations were based on four (4) different real engine types: General Electric's LM6000 and LM2500+G4, and Rolls Royce's MT50 and MT30. These were correspondingly modeled within ComPASS™, reflecting both physical and performance characteristics, and then the number of engines was varied in order to explore the powering requirements trade space and the impacts on overall ship size. The results of this trade-off analysis are shown in Table 3-4.

To assess the general reasonableness of the chosen design, the Transport Efficiency (WV/P) vs. Volumetric Froude Number of the design is shown plotted in Figure 3-5 as SAIC HSSL AL Ph II and is compared to the earlier HSSL baselines and other vessels that have been built including Monohulls, Multihulls, SWATH, Hydrofoils, SES, ACV's and Hydroplanes.

This Transport Efficiency (TE) combines both hullform lift-to-drag ratio and propulsive efficiency, and the chart of Figure 3-5 defines the overall state-of-the-art of the propulsion challenge based upon the Circle-Q and K relationships made famous by William Froude in the late 1800's. It is something like a return on investment where P is the installed power of the investment, W is the ship's displacement, and V is the ship's maximum speed, the product (WV) of which is the return. The challenge is that as speed increases, the return on investment ratio falls rapidly. This is due to a number of factors, the main factor of which is the rapid increase in drag (D). Over the years, this has been

overcome primarily by attempts to disconnect the vessel from the water, and we see on the chart these attempts with Hydrofoils, SES, ACV's, and Hydroplanes (even WIGS) occupying the best positions on the high-speed right-hand side of the chart. However, reducing contact with the water tends to reduce the propulsive efficiency, or coefficient $\eta'$ of the propulsion system (D.V/P), so a trade-off ensues to reduce drag without unduly decreasing propulsive efficiency $\eta'$ or, in other words, maximizing Transport Efficiency (TE) by maximizing both the lift-to-drag ratio L/D (or W/D) and the propulsive coefficient $\eta$, [where TE = WV/P = W$\eta$/D = (L/D)$\eta$]. Thus, the proposed HSSL baseline plots very favorably compared to other vessel types.

**Table 3-4 – Comparison of Baseline Design with Ships having other Power Plant Options and Revised Drag**

CHOSEN DESIGN

| SIX ENGINE CONFIGS, DRAG@ 43 kts using MATCHED TO 2.14 million lbf | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Description** | REV 0<br>Baseline Configuration<br>Step Increment Propulsion | LM6000 - 59900 HP<br>Baseline w/Increased<br>Drag & User Defined Eng | LM6000 8 Engines<br>Baseline w/Increased<br>Drag & User Defined Eng | LM2500+G4 - 47370 HP<br>Baseline w/Increased<br>Drag & User Defined Eng | MT50 - 67051 HP<br>Baseline w/Increased<br>Drag & User Defined Eng | MT50 8 Engines<br>Baseline w/Increased<br>Drag & User Defined Eng | MT30 - 48277 HP<br>Baseline w/Increased<br>Drag & User Defined Eng |
| **100 WT (LT)** | 3,638 | 3,682 | 3,703 | 3,760 | 3,674 | 3,690 | 3,719 |
| **200 WT (LT)** | 1,663 | 1,860 | 1,927 | 1,871 | 1,866 | 2,000 | 1,897 |
| **300 WT (LT)** | 281 | 286 | 288 | 295 | 284 | 286 | 291 |
| **400 WT (LT)** | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| **500 WT (LT)** | 1,919 | 1,947 | 1,955 | 2,000 | 1,934 | 1,937 | 1,976 |
| **600 WT (LT)** | 558 | 565 | 570 | 579 | 569 | 563 | 574 |
| **F40 WT (LT)** | 6,560 | 6,729 | 6,734 | 7,072 | 6,562 | 6,523 | 6,878 |
| **Draft, ft** | 34.5 | 35.3 | 35.5 | 36.4 | 35.1 | 35.2 | 35.9 |
| **Displ, LT** | 19,320 | 19,789 | 19,918 | 20,324 | 19,608 | 19,743 | 20,077 |
| **Drag @ 38.3 kts, lbf** | 1,437,421 | 1,714,658 | 1,715,854 | 1,721,700 | 1,723,849 | 1,715,062 | 1,721,660 |
| **Drag @ 43 kts, lbf** | 1,791,868 | 2,140,744 | 2,140,858 | 2,141,290 | 2,144,097 | 2,140,399 | 2,143,977 |
| **# of Propulsors** | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **# of Main Engines** | 4 | 7 | 8 | 9 | 7 | 8 | 9 |
| **Pwr per Engine, hp** | 125,000 | 59,900 | 59,900 | 47,370 | 67,051 | 67,051 | 48,277 |
| **Total installed pwr, hp** | 500,000 | 419,300 | 479,200 | 426,330 | 469,357 | 536,408 | 434,493 |
| **Fuel Consump @ 38.3 kts, lb/hr** | 111,383 | 114,256 | 114,345 | 120,087 | 111,432 | 110,756 | 116,786 |
| **Spd at Full Load, kts** | 46.4 | 41.4 | 43.4 | 41.7 | 43.1 | 44.5 | 41.9 |
| **Spd at Med Load, kts** | 49.2 | 43.8 | 45.2 | 44.1 | 44.7 | 46.9 | 44.3 |
| **Avg Max Speed, kts** | 47.8 | 42.6 | 44.3 | 42.9 | 43.9 | 45.7 | 43.1 |

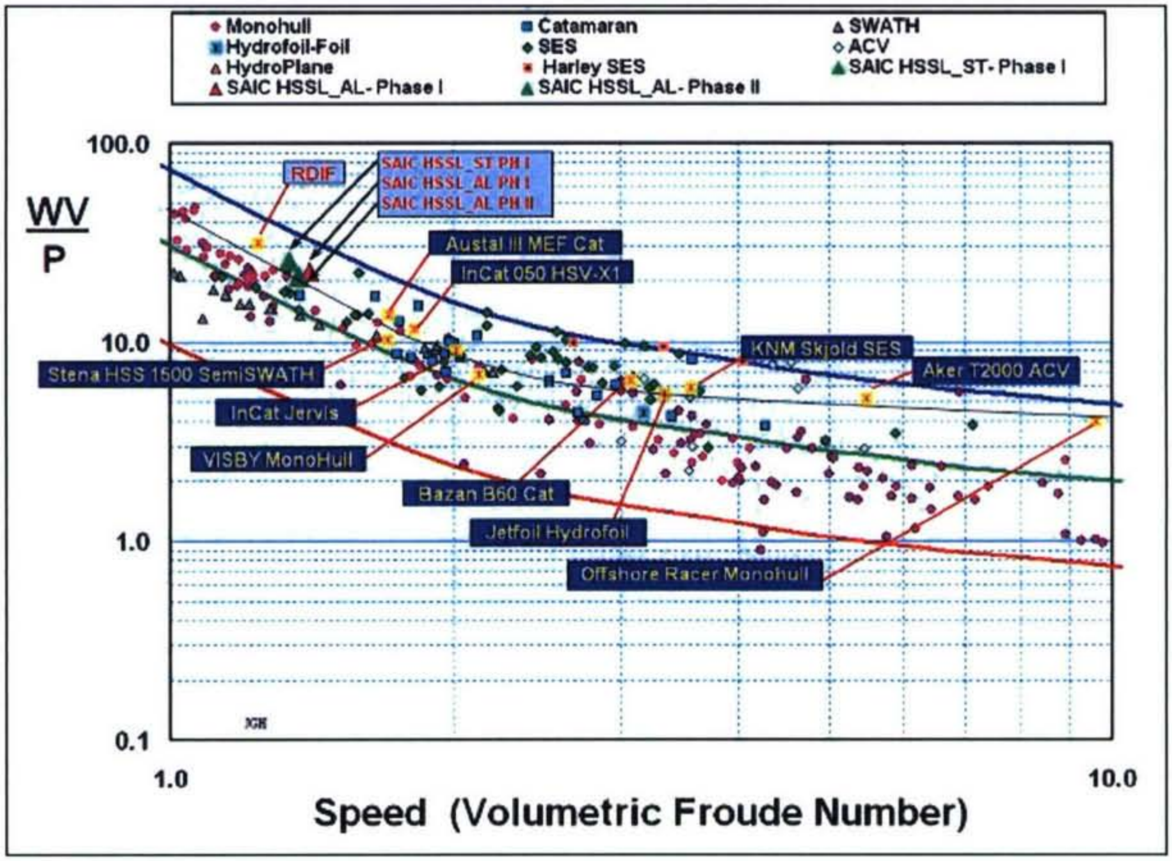


**Figure 3-5 – Comparison of Transport Factor for HSSL and other Designs & Existing Ships**

## 3.5 Hullform and Hydrodynamic Performance

This section provides a brief description of the work conducted to optimize the below water shape of the demihulls to minimize ship drag and the brief analysis and model tests conducted to characterize ship motions and accelerations when operating in a seaway.

### 3.5.1 Hull Configuration

The subject vessel is a concept conceived by CDIM-SDD that can easily transform itself to operate either as a Catamaran, a SWATH, or as an SES. This concept was developed to challenge the capability of the design tools being developed by a team headed by SAIC in performance of the ONR HSSL Subtopic-B program of work. The catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability, and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping, and the SES because of its ability to afford shallow draft with end seals deployed and to combine with the SWATH to enhance seakeeping at low speed. This latter combination is achieved by ballasting the vessel to transform from a Cat mode to a SWATH mode in combination with deploying the cushion end seals and a cushion divider, and supplying air to the

cushion as in an SES, with active control of cushion vent valves and hence control of cushion pressure fore and aft of the divider.

One of several serious challenges for successfully supporting and sustaining the operations of military marine expeditionary forces ashore will be the safe, reliable, and efficient transfer of heavy equipment and cargo at sea. This transfer would need to be from a Sea Base or MPF(F) Ship to high-speed surface connectors, such as the ONR HSSL, for shipment of cargo to forces ashore via shallow-draft ports. This is in addition to the challenge of efficiently transporting very large payloads at high speeds over very long distances at sea. The primary issue for the transfer of equipment at the Sea Base is the need to mitigate wave-induced relative motions between ships in sea states 4/5 to enable safe yet rapid heavy-vehicle transfer (loading-unloading heavy armored combat vehicles). This has been recognized as a serious challenge by the U.S. Navy, and numerous techniques have been and continue to be tried with mixed success. The objective of the proposed program of work, therefore, was to conceive of a near-term, affordable, shallow-draft, heavy-lift, High-Speed Surface Connector (HSC) that would make motion compensation requirements for cargo transfer systems under development less demanding and therefore have a higher probability of success in satisfying overall Sea Basing mission objectives.

The HSC should ideally:

1. be capable of efficiently transporting very large payloads (4000 tons) at high speeds (greater than 40 knots) over long distances (greater than 5000 nautical miles).
2. have shallow draft to permit access to as many foreign ports as possible.
3. have low pitch, heave and roll motions in response to heavy seas.
4. require reliable low-risk technologies that can result in a viable near-term affordable solution.

Requirements 1 and 4 are probably best satisfied by a multihull concept, requirement 2 by an SES concept, and requirement 3 by a SWATH concept. In order to satisfy all four requirements, a hybrid of all three ship concepts was conceived. The design is operationally transformable, making it far superior for every element of the mission than any of the three individual concepts alone. Figure 3-6 illustrates the model that was tested of this hybrid design.

**Figure 3-6 – HSSL Model**

The SWATH/SES combination is achieved by ballasting the vessel to transform it from Cat mode to SWATH mode while simultaneously deploying the cushion end seals and cushion divider. Air is then supplied to the cushion as in a SES, but with active control of cushion vent valves located fore and aft of the cushion divider to control cushion pressure. The large aerostatic forces and moment arms available from the SES split cushion are then advantageous in providing active control of heave and pitch motion from relative-motion feedback on a hull that already has reduced seaway excitation forces from the Small Waterplane Area of the SWATH mode. This SES concept has already seen limited demonstration by NSWCCD in early 1991. The combination of ballasting/de-ballasting and end-seal deployment to control draft offers the ability to also adjust deck height for cargo transfer in port or at the sea base and to detune the ship's response in a seaway as it is being loaded or unloaded. Active roll control could also be arranged, if needed, with the addition of an inflated longitudinal keel or with active control of waterjet vectoring. Additionally, deballasting can be assisted with SES cushion pressure.

This approach could be used for loading at zero forward speed alongside the Sea Base or for low-speed "ship-stern-to-HSC-bow" loading when the HSC is being towed in a partial self-propelled mode with maneuvering control at a most favorable heading to the sea. Note that this is a concept not available to non-air-cushion type vessels, which generally need significant forward speed through the water to achieve useful vertical plane motion control. Also note that at no time are the SES seals used for high speed, so their life expectancy should not be a major issue.

### 3.5.2 Design Considerations

An initial hullform design was developed by CDIM-SDD during the first phase of the ONR HSSL, Subtopic-B effort. This design introduced the major features of the concept described above: low-speed SWATH operation for good seakeeping during at-sea cargo transfer, catamaran for high-speed operation, and SES for draft minimization and motion control in SWATH operation. The initial design was prismatic in nature, as shown in Figure 3-7, with the thought that significant lift could be generated by the sidehulls to minimize drag in the catamaran mode. However, because the payload and range goals resulted in a heavy vessel, the sidehulls of the catamaran were heavily loaded and were forced into operating in the displacement mode, and this was not apparent until after the study was started.

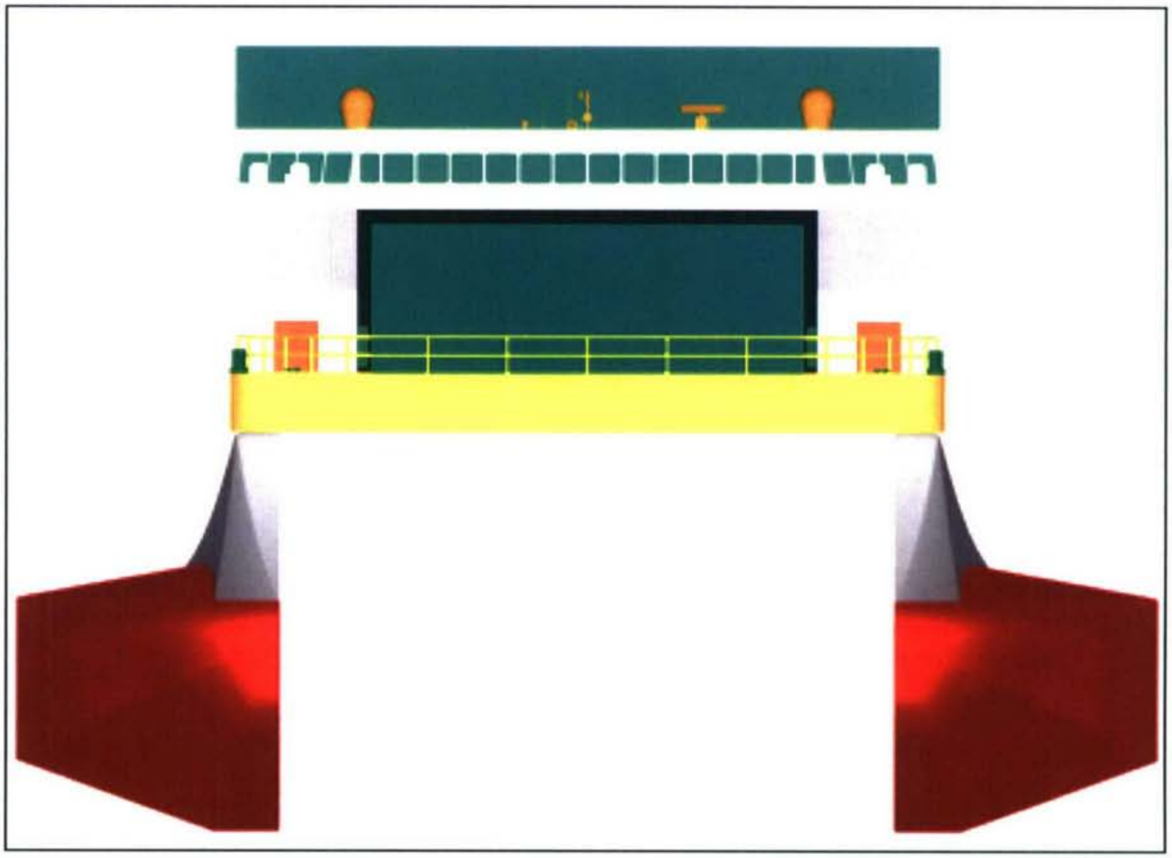

**Figure 3-7 – Original Hull Design Concept**

As part of the second phase of the ONR HSSL Subtopic-B effort, CFD and numerical optimization techniques were used to evaluate and update the design. The potential flow CFD code Das Boot was used by SAIC to determine the drag curve of the initial hull. This analysis determined that the drag model employed in ComPASS™ was under-predicting the drag of the design. The drag model of ComPASS™ was updated using the Das Boot results and experimental results to account for separation ratio and other parameters. It should be noted here that all versions of ComPASS™ prior to this upgrade employed the same method of calculating the wave-making drag of twin-hull vessels.

The wave resistance of a single hull was calculated according to the Holtrop-Mennen equations (or the Series 64 curve fits, if applicable) and then simply multiplied by two for both demihulls. The two major disadvantages of this approach were:

1. The separation between the hulls was not taken into account; consequently, the interaction effects of the two wave trains were neglected.
2. The range of the data on which the equations are based limits the accuracy of the Holtrop-Mennen predictions.

The update involved the implementation of an empirical approach, based on a series of model tests conducted at the University of Southampton, with ten hullforms of varying combinations of slenderness and separation ratios. This data is presented in Reference 5.

Using this model test data, a series of speed-independent regression equations were developed, based on functions of slenderness and separation ratios, which were blended with the existing Holtrop empirical routines in order to be able to assess hullforms with lower Froude numbers. The resulting algorithms were implemented in an updated version of ComPASS™. These were subsequently adjusted for the Das Boot drag results via a Point Surrogate modeling process, defined in more detail in Reference 6. In addition, details of the upgrades made to the ComPASS™ catamaran drag routine are covered in Reference 3, a portion of which is included in Appendix C along with a description of other hullform-related upgrades.

Das Boot was also used with the optimization software SHAPE to determine if the drag of the baseline design for the concept could be reduced through modification of the hull shape below the catamaran waterline. The surface was allowed to move +/- 5 feet normal to the baseline design. In addition, the effect of transom size was investigated. An optimum hull shape was determined using the computer codes which redistributed the volume of the hulls while keeping the displacement constant. It was also found that reducing the size of the transom was beneficial. The optimized hull shape, with contours of distance to baseline shape, is shown in Figure 3-8.

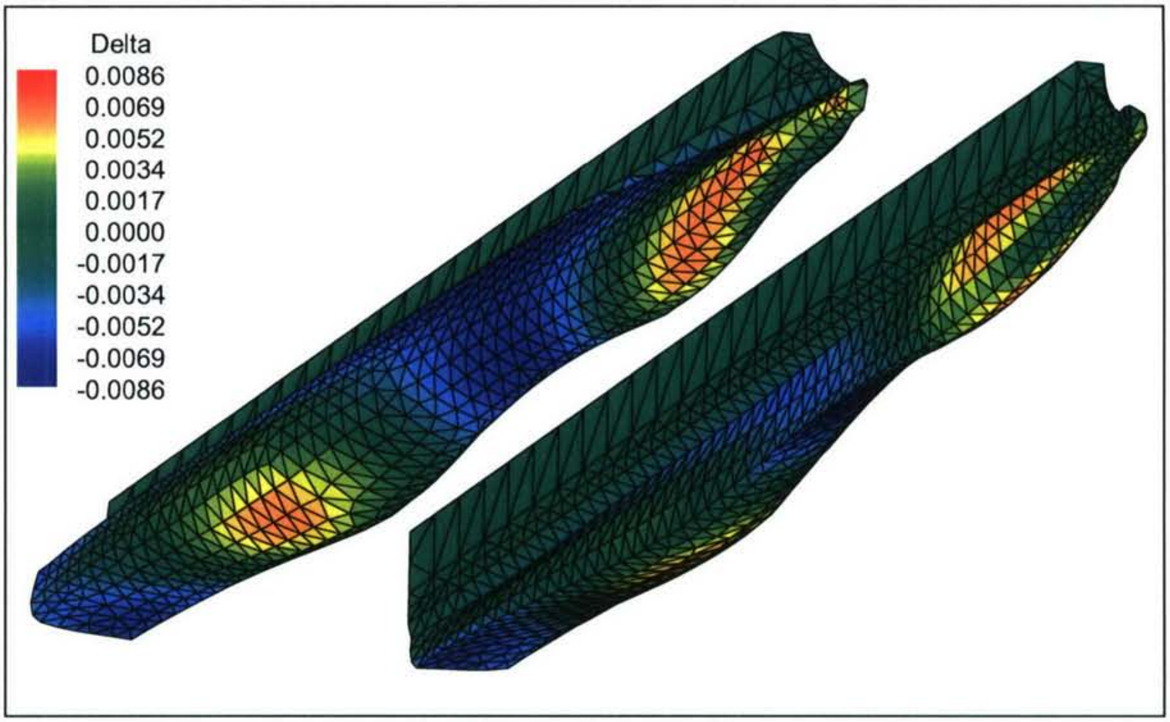


**Figure 3-8 – Optimized Hull Deformation Contours**

This optimized hullform was then evaluated for the effect of separation ratio, displacement and demihull toe-in angle. These studies indicated that the optimized hullform was dependent on the separation ratio so that any increase or decrease in the parameter caused the drag to increase. Also, small amounts of toe-in or toe-out were not found to provide any drag benefit. The changes in drag due to displacement changes were incorporated into an updated drag model within ComPASS™.

While alternative concepts such as semi-SWATH were considered, the optimized hullform was chosen as the basis for further development in order to take advantage of the computational work performed. ComPASS™ was run with its updated drag model to determine a new balanced design. The updated drag model indicated that even with the optimized hullform, the ship would have greater total drag than initially calculated. This required the updated design to have a larger displacement of 19,630 tons.

In order to use the optimized hull shape in further design work, it needed to be converted into a CAD model. The SHAPE code uses a faceted geometry definition where the surface is represented by an unstructured triangular mesh. The faceted geometry was imported into the modeling software Rhinoceros3D as a mesh. Meshes are the native representation in Rhino3D of triangular unstructured surfaces. Several non-uniform, rational B-spline (NURBS) surfaces were then created in Rhino3D to model the hull, bow and struts which matched the faceted geometry as closely as possible. These surfaces were then used to determine the initial hydrostatic properties of the design using RhinoMarine software.

The faceted surfaces imported from SHAPE required significant fairing and updating. SHAPE had introduced a number of artifacts due to various constraints imposed on the optimization process such as a requirement that the inner surface of the demihulls remain planer, vertical and parallel surfaces. The surface shape changes of the hull under the design waterline caused there to be shelves on the inner side of the hulls where they joined the struts and a small ledge on the outboard side of the hulls near the bow. In addition, the bows of the hulls were coarsely defined in the faceted geometry and required shaping and fairing. The inboard shelves were removed by fairing the sectional curves local to the feature while keeping the areas constant. The small ledge was smoothed in a similar fashion, but not removed in order to be used as a small fence for keeping water off of the top of the catamaran hulls. The bows were shaped to allow for wave piercing to minimize slamming and to keep the volume distribution and shape reasonably similar to the numerically optimized shape. The hull was then updated in an iterative manner to enhance the overall fairness while keeping both the inboard/outboard demihull and total sectional areas as close as possible to the initial hydrostatic values. A comparison of the initial faceted geometry and the faired geometry is shown in Figure 3-9.

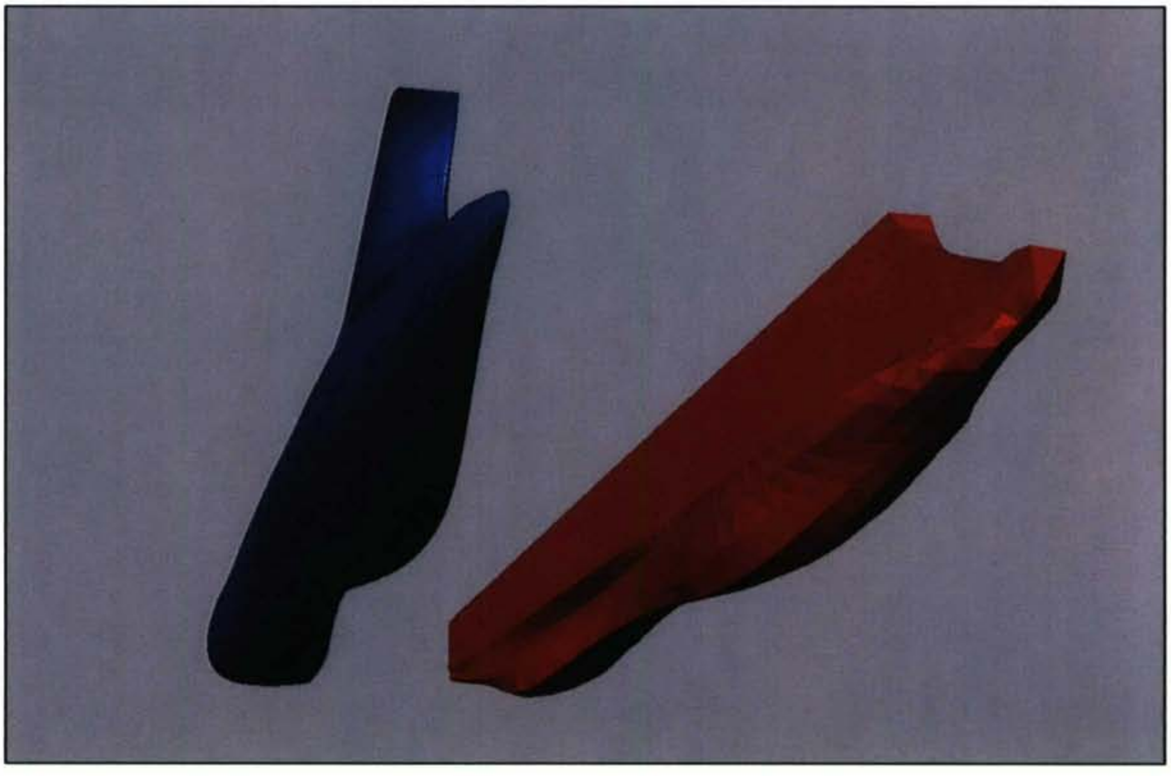

**Figure 3-9 – Faceted & Faired Hullforms**

Additional modifications of the hull were made to incorporate waterjets, as shown in Figure 3-10, incorporate SES seals, and to increase displacement to the value indicated by ComPASS™ using the updated drag model. Based on SAIC's CFD results, the transom was made as small as possible while being big enough to house the waterjets and associated hardware. These changes were again made in an iterative manner, keeping the

sectional area curves as similar as possible. The initial sectional area curves for the optimized hullform and for the faired hullform are shown in Figure 3-11.

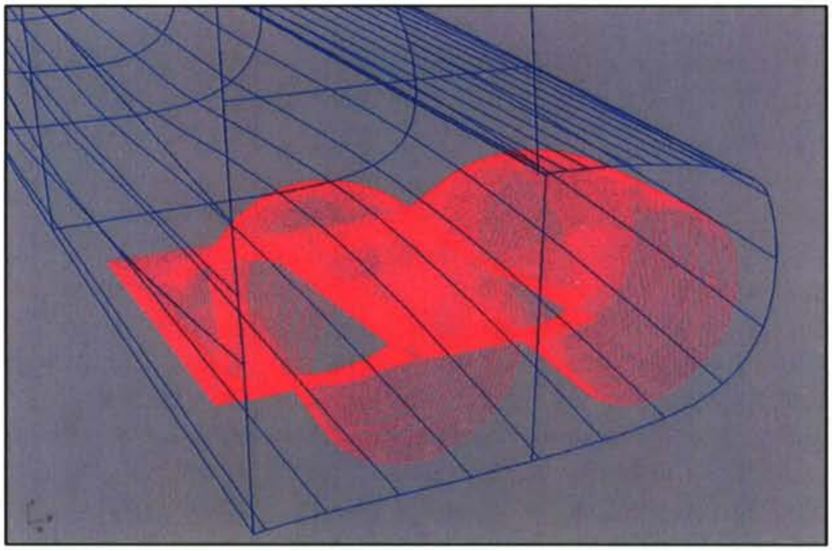

**Figure 3-10 – Waterjets Incorporated into Hull**

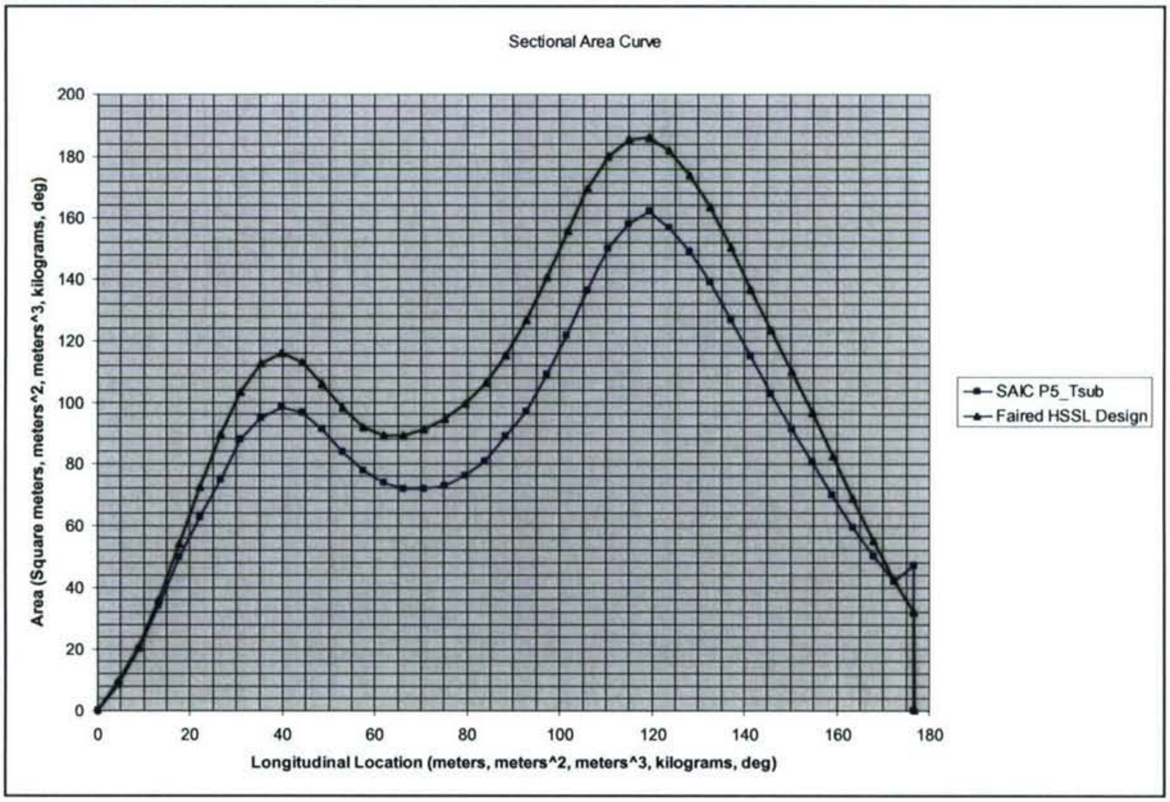


**Figure 3-11 – Comparison of Sectional Area Curves**

The resulting hull design was used to build a 1/55$^{th}$-scale model of the HSSL design which was tested at the Naval Surface Warfare Center, Carderock Division, in December

2006. Due to the unusual shape of the hull, there was concern that the boundary layer would separate and additional drag would result, especially at model scale. To investigate this possibility, the RANS code CFX was used to model the flow around the hull at model scale using a double body approximation of the free surface. The computation did not indicate any problem with boundary layer separation and an image of pressure contours with surface streamlines is shown in Figure 3-12.

**Figure 3-12 – Model Scale Pressures and Surface Streamlines in SWATH Mode Computed with CFX**

Complete results of the model test are documented in Reference 2. With regard to the hull design, two areas were identified during the model test for refinement. First, the fairing of the struts at the bow was too blunt and caused a significant amount of water to run up the struts when operating in catamaran mode. The second observation was that too much water was washing across the top of the catamaran hulls during operation in both calm water and various sea states. This was due to insufficient freeboard on the catamaran hulls and the ledge on the outboard bows was not large enough to deflect all the water washing over the bow. In order to improve the hull based on these observations, the hull struts were modified to increase the length of the fairing on the bow of the struts and decrease the entry angle of these fairings to less than half of the design used in the model test. The freeboard of the catamaran hulls was increased by over a meter and the tops of the catamaran were given additional slope away from the struts to quickly shed any water that washed over the hulls.

## 3.5.3 Seakeeping Assessment

This section provides an analytical examination of vessel seakeeping in the catamaran mode and the results of model tests conducted with the vessel in the catamaran, SWATH and combined SWATH/SES mode with and without SES motion control.

### *3.5.3.1 Seakeeping Analytical Analysis*

Where more detailed estimates of seaway induced motions and loads are required in the early stages of the design cycle, ComPASS™ is typically utilized in combination with other subject-specific stand-alone programs and codes such as the University of Michigan developed seakeeping prediction tool SHIPMO (see University of Michigan Department of Naval Architecture and Marine Engineering Report No. 89-2 for details). SHIPMO computes the 6-Degree of Freedom (DOF) motion responses, shear, and bending moments of monohull or catamaran vessels in the frequency domain based on the two-dimensional, linear strip theory of Salvesen, Tuck, and Faltinsen (1970). Like ComPASS™, SHIPMO is ideal for use at the earliest stages of design due to its rapid speed of execution, which allows the generation of motion and load statistics for the full range of speeds, headings, and sea states in a matter of seconds.

SHIPMO input files are currently developed manually in a process that typically requires approximately one man-day. Once the development of an input file is complete, sectional and waterplane areas, as well as displacement from the SHIPMO output file, are compared to actual values from the hullform geometry to ensure accuracy.

Although SHIPMO is convenient due its ease of use and its rapid execution, the simple strip-theory upon which the underlying code is based has several limitations and shortcomings when it comes to HSSL-type vessel applications and geometries. Some of the more apparent limitations are summarized as follows:

The theory assumes a linear relationship between excitation forces (i.e. seaway spectral conditions) and vessel responses, which is typically only appropriate for small amplitude motions, but can remain reasonably linear for much of a ship's mission and in all but extreme conditions.

The theory is two-dimensional in nature, and therefore does not consider hydrodynamic interactions between each section or "strip" utilized to define the vessel geometry. This limits the applicability and accuracy of the theory to lower speeds, with typical upper limits established at length-based Froude numbers of approximately 0.30 – 0.35. At higher speeds, the theory begins to break down and results are of questionable accuracy. The HSSL concept described herein is designed for operation at Froude numbers in excess of 0.5.

Models are constructed up to the undisturbed static waterline only, and therefore the effects of geometrical features occurring above the waterline, such as flare or tumblehome, are not considered (e.g. the program assumes the vessel is wall sided above the static waterline). This is a serious limitation for the HSSL concept proposed herein

because of the proximity of the top of the demihull to the undisturbed free surface when the vessel is operating at full load in catamaran mode. The rapid changes in waterplane area that occur as the vessel responds to the seaway will not be accounted for.

Because the theory operates in the frequency domain, response time-histories are not available, making the definition of transient, non-linear events such as cross-deck slamming and waterjet emergence difficult to quantify.

In spite of these limitations, when utilized in combination with higher-fidelity analytical tools, frequency domain codes such as SHIPMO can still operate effectively as coarse filters for use in rapid identification of particular combinations of speed, heading, sea state, and vessel loading that are likely to exhibit higher motions and loads and therefore serve as design drivers. In this fashion, tools such as SHIPMO can increase the analytical efficiency of the more accurate, but slower executing, high level tools.

Predictions of seaway induced motions for the HSSL design (in catamaran mode) at 43 knots generated utilizing SHIPMO are shown in Table 3-5, which include the Root-Mean-Square (RMS) statistics for global vessel motions in the lateral and vertical planes in NATO sea state 4. Note that certain results included in these Tables appear to be of questionable accuracy, most notably the predictions of planar motions such as surge and sway in stern quartering seas (headings of 30 and 60 degrees). The results appear to be consistent with those from our earlier hullform development, which supported the SAIC Team's work on Subtopic B, and which are presented in
Table 3-6.

Table 3-7 shows the percent difference of the current hullform motions from the earlier hullform motions.

As noted previously, for the purposes of this study, NATO standard sea state definitions have been assumed. In sea state 4, this reflects a significant wave height of 6.17 feet and a most-probable modal period of 8.8 seconds.

**Table 3-5 – SHIMPO-Predicted RMS Motions for the HSSL design (Cat mode) in SS4**

| VESSEL HEADING (deg) | SURGE (ft) | SWAY (ft) | HEAVE (ft) | ROLL (deg) | PITCH (deg) | YAW (deg) |
|---|---|---|---|---|---|---|
| 180 (head) | 0.07 | 0.00 | 0.66 | 0.00 | 0.24 | 0.00 |
| 150 | 0.16 | 0.17 | 1.32 | 0.10 | 0.37 | 0.08 |
| 120 | 0.57 | 0.29 | 4.65 | 0.30 | 1.41 | 0.13 |
| 90 | 0.16 | 0.73 | 1.07 | 1.85 | 0.38 | 0.09 |
| 60 | 48.90 | 33.80 | 0.47 | 0.35 | 0.17 | 0.42 |
| 30 | 154.00 | 110.00 | 0.30 | 0.26 | 0.15 | 1.05 |
| 0 | 6.30 | 0.00 | 0.36 | 0.00 | 0.14 | 0.00 |

**Table 3-6 – SHIMPO-Predicted RMS Motions for the Phase I HSSL design (Cat mode) in SS4**

| VESSEL HEADING (deg) | SURGE (ft) | SWAY (ft) | HEAVE (ft) | ROLL (deg) | PITCH (deg) | YAW (deg) |
|---|---|---|---|---|---|---|
| 180 (head) | 0.12 | 0.00 | 1.31 | 0.00 | 0.36 | 0.00 |
| 150 | 0.06 | 0.05 | 0.78 | 0.07 | 0.19 | 0.03 |
| 120 | 0.15 | 0.32 | 1.60 | 0.34 | 0.36 | 0.08 |
| 90 | 0.11 | 0.77 | 1.25 | 2.12 | 0.43 | 0.10 |
| 60 | 79.70 | 142.00 | 0.46 | 0.39 | 0.16 | 1.54 |
| 30 | 196.00 | 119.00 | 0.42 | 0.28 | 0.19 | 1.14 |
| 0 | 7.67 | 0.00 | 0.61 | 0.00 | 0.28 | 0.00 |

**Table 3-7 – % Difference in SHIMPO-Predicted RMS Motions between the current and Phase I HSSL designs (Cat mode) in SS4**

| VESSEL HEADING (deg) | SURGE (ft) | SWAY (ft) | HEAVE (ft) | ROLL (deg) | PITCH (deg) | YAW (deg) |
|---|---|---|---|---|---|---|
| 180 (head) | -35.60% | 0.00% | -49.39% | 0.00% | -32.22% | 0.00% |
| 150 | 152.34% | 218.68% | 68.58% | 42.17% | 96.32% | 136.96% |
| 120 | 285.14% | -9.03% | 190.63% | -12.61% | 292.76% | 57.64% |
| 90 | 39.29% | -4.95% | -14.40% | -12.74% | -10.54% | -8.51% |
| 60 | -38.64% | -76.20% | 0.65% | -10.18% | 9.68% | -72.47% |
| 30 | -21.43% | -7.56% | -28.23% | -4.00% | -23.56% | -7.89% |
| 0 | -17.86% | 0.00% | -40.10% | 0.00% | -50.00% | 0.00% |

SHIPMO-predicted vertical and lateral accelerations for the Initial Baseline HSSL design concept at several key locations in sea state 4 are given in Table 3-8 and Table 3-9. Coordinates assumed for the locations onboard the HSSL are as follows:

Bridge:

- Longitudinal Position = 89.7 feet aft FP
- Lateral Position = 0.0 feet off CL
- Vertical Position = 83.4 feet above baseline

Wet Deck:

- Longitudinal Position = 140.0 feet aft FP
- Lateral Position = 0.0 feet off CL
- Vertical Position = 54.6 feet above baseline

Main Deck – Bow Edge:

- Longitudinal Position = 3.0 feet aft FP
- Lateral Position = 0.0 feet off CL
- Vertical Position = 68.7 feet above baseline

Main Deck – Amidships:

- Longitudinal Position = 277.3 feet aft FP
- Lateral Position = 0.0 feet off CL
- Vertical Position = 68.7 feet above baseline

Accelerations reported in Table 3-8 and Table 3-9 are statistical RMS values, listed in units of feet per second squared for operation at 43 knots in sea states 4 & 6, respectively. Longitudinal accelerations are also generated in SHIPMO, but are not reported here.

Derived motion quantities, such as the rate of cross-deck slamming, waterjet inlet emergence, etc., are not reported directly by the SHIPMO program, although the code does possess the capability to generate statistical summaries of relative motions and relative velocities (e.g. relative to the water surface) at any point in space, from which statistical estimates of the probability of slam and emergence occurrences can be developed in post-processing.

Additionally, SHIPMO operates strictly in the frequency domain, and therefore time histories of seaway induced motions and accelerations are not available.

**Table 3-8 – SHIMPO-Predicted RMS Accelerations for the HSSL design (Cat mode) in SS4**

| VESSEL HEADING (deg) | BOW CL (ft/sec$^2$) | | BRIDGE CL (ft/sec$^2$) | |
|---|---|---|---|---|
| | Vertical | Lateral | Vertical | Lateral |
| 180 (head) | 1.240 | 1.410 | 0.843 | 1.060 |
| 150 | 1.040 | 1.640 | 0.707 | 1.280 |
| 120 | 1.510 | 6.120 | 1.110 | 4.760 |
| 90 | 1.000 | 1.830 | 1.190 | 1.410 |
| 60 | 0.429 | 0.161 | 0.306 | 0.126 |
| 30 | 0.344 | 0.272 | 0.274 | 0.232 |
| 0 | 0.000 | 0.344 | 0.000 | 0.309 |

**Table 3-9 – SHIMPO-Predicted RMS Accelerations for the HSSL design (Cat mode) in SS4**

| VESSEL HEADING (deg) | WET DECK CL (ft/sec$^2$) | | DECK AMIDSHIP CL (ft/sec$^2$) | |
|---|---|---|---|---|
| | Vertical | Lateral | Vertical | Lateral |
| 180 (head) | 0.452 | 0.939 | 0.486 | 0.766 |
| 150 | 0.380 | 1.190 | 0.407 | 1.300 |
| 120 | 0.711 | 4.370 | 0.567 | 4.700 |
| 90 | 0.681 | 1.240 | 0.837 | 0.777 |
| 60 | 0.172 | 0.112 | 0.144 | 0.085 |
| 30 | 0.141 | 0.217 | 0.119 | 0.184 |
| 0 | 0.000 | 0.297 | 0.000 | 0.279 |

#### *3.5.3.2 Recommendations for Future Study*

While there was not time or resources available for this study to adequately evaluate alternative concepts such as SWATH or Semi-SWATH hullforms, it would be worthwhile to evaluate these types of geometries in future studies. In addition, further

computational and experimental studies would be useful to more fully examine the effect of design parameters such as demihull spacing, length-to-beam ratio, length-to-draft ratio and volume distribution. Also, computation of the effect of waterjet operation on the hull would be useful, as well as the addition of seakeeping to the numerical optimization process.

#### 3.5.3.3 Seakeeping Model Tests

Tests of a $1/55^{th}$-scale hydrodynamic model of the CDI designed HSSL with SAIC Das Boot revised demihulls were conducted at DTMB Carderock MD in December 2006. These tests were conducted for ONR to provide data to the SAIC Team to help validate the analytical tools being developed in support of their HSSL Subtopic B program of work.

The model was tested in head seas on DTMB's Carriage III with a rig giving the model freedom to heave and pitch, but fixed in surge, roll, sway and yaw. Tests were conducted for a range of forward speeds, sea states, and vessel displacement, and in the required different modes of operation of the concept that included Catamaran, SWATH, and SWATH with SES motion control. Other non-seakeeping related tests were also conducted including tests to demonstrate the concept's ability to achieve the desired shallow draft.

Figure 3-13, Figure 3-14, and Figure 3-15 compare RMS vertical accelerations for the HSSL model at full load in High-Speed Catamaran mode while heading into sea states 4 and 5. The model experienced the lowest motions at the full-scale design speed of 43 knots in both sea states for the $CAT_{FULL}$ ballast configuration. It is also worth noting that motions for the $CAT_{FULL}$ configuration were larger than for the $CAT_{LIGHT}$ configuration at 25 knots full-scale speed, but the opposite was true at 43 knots. There is also a slight increase in RMS vertical accelerations for all configurations from sea state 4 to sea state 5, which is to be expected.

Figure 3-16 compares model motions in terms of RMS heave displacement for three forward speeds, two sea states, and four operating conditions. Figure 3-17 compares similar results for pitch motion. Both figures compare RMS motions for the four configurations examined with the HSSL model in the Loading and Unloading SWATH mode. Heave motion was lowest in the Pure SWATH mode, and the motion controller did little to help motion in heave. This result is to be expected since the controller was using minimum bow heave as the objective function; thus, the motions at other vessel locations can and often do increase.

The controller performed markedly better in controlling pitch and produced improvements in bow heave motions for some of the tested conditions, as can be seen in Figure 3-18. Further reductions in bow heave would be expected if the results from the first test series were to be used to appropriately pre-tune the bow acceleration filter array (in which case, subsequent testing may result in further increases of CG and stern heave motions while bow heave is further reduced). For most tested conditions, Pure SWATH and SWATH-SES with the motion controller active resulted in similar RMS pitch angles.

In sea state 6 at 10 knots, however, the motion controller minimized pitch motion better than was achieved with the Pure SWATH configuration.

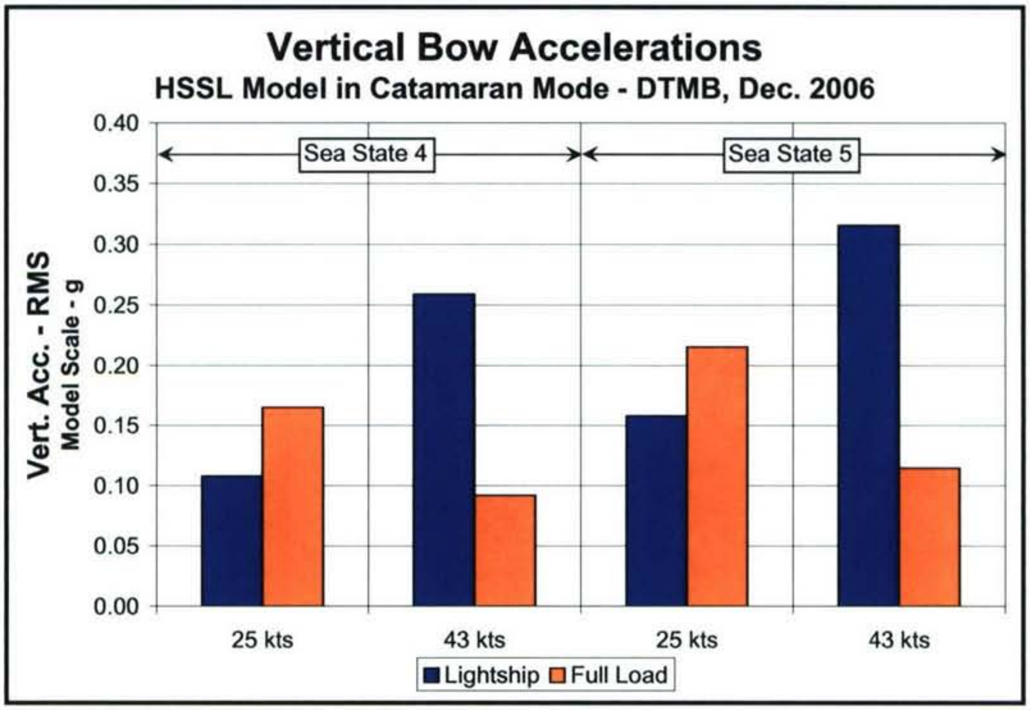


**Figure 3-13 – Bow RMS Vertical Accelerations of HSSL Model in Catamaran Mode**

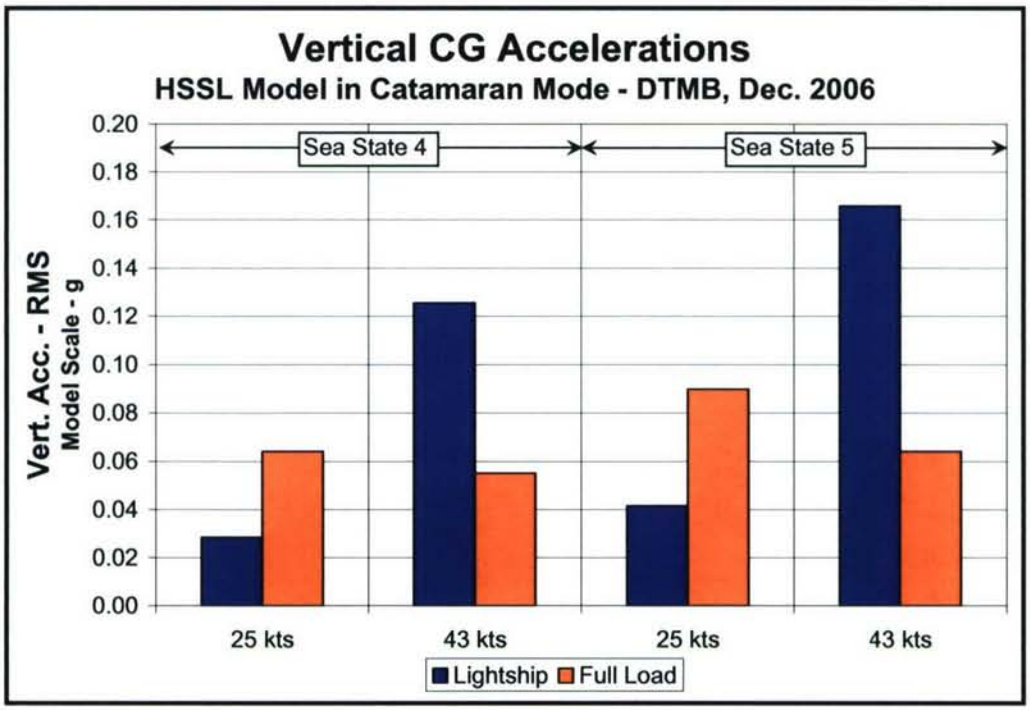


**Figure 3-14 – CG RMS Vertical Accelerations of HSSL Model in Catamaran Mode**

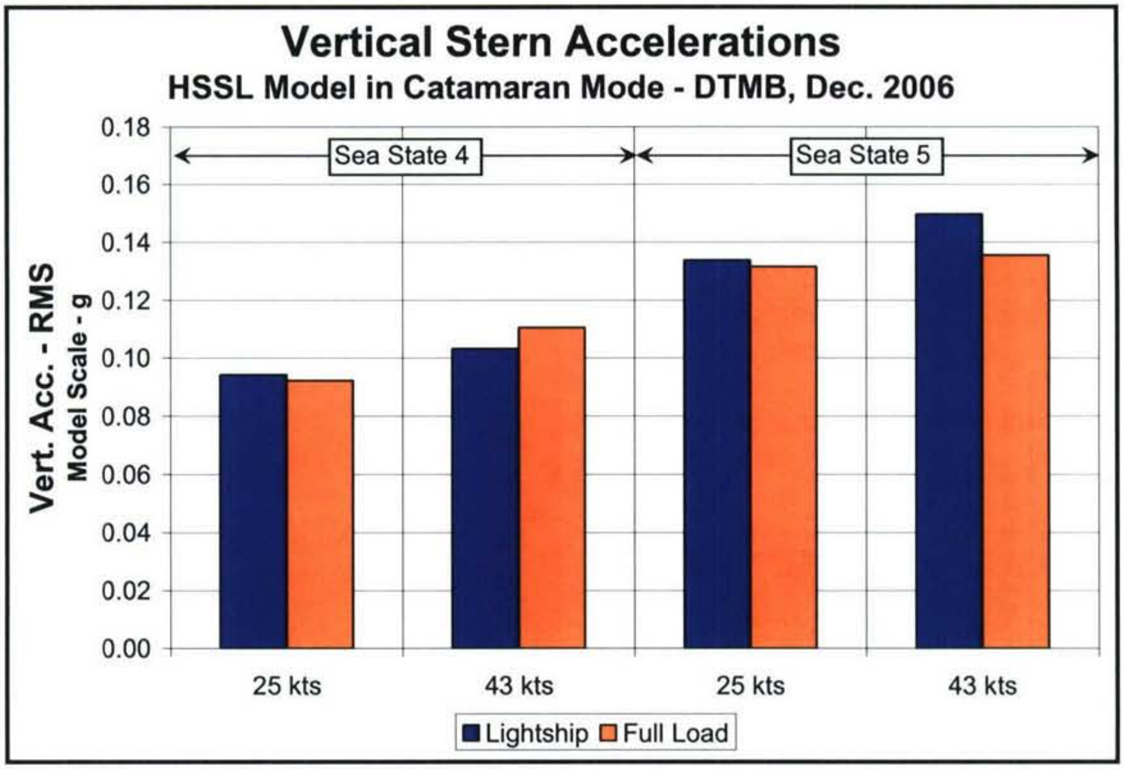


Figure 3-15 – Stern RMS Vertical Accelerations of HSSL Model in Catamaran Mode

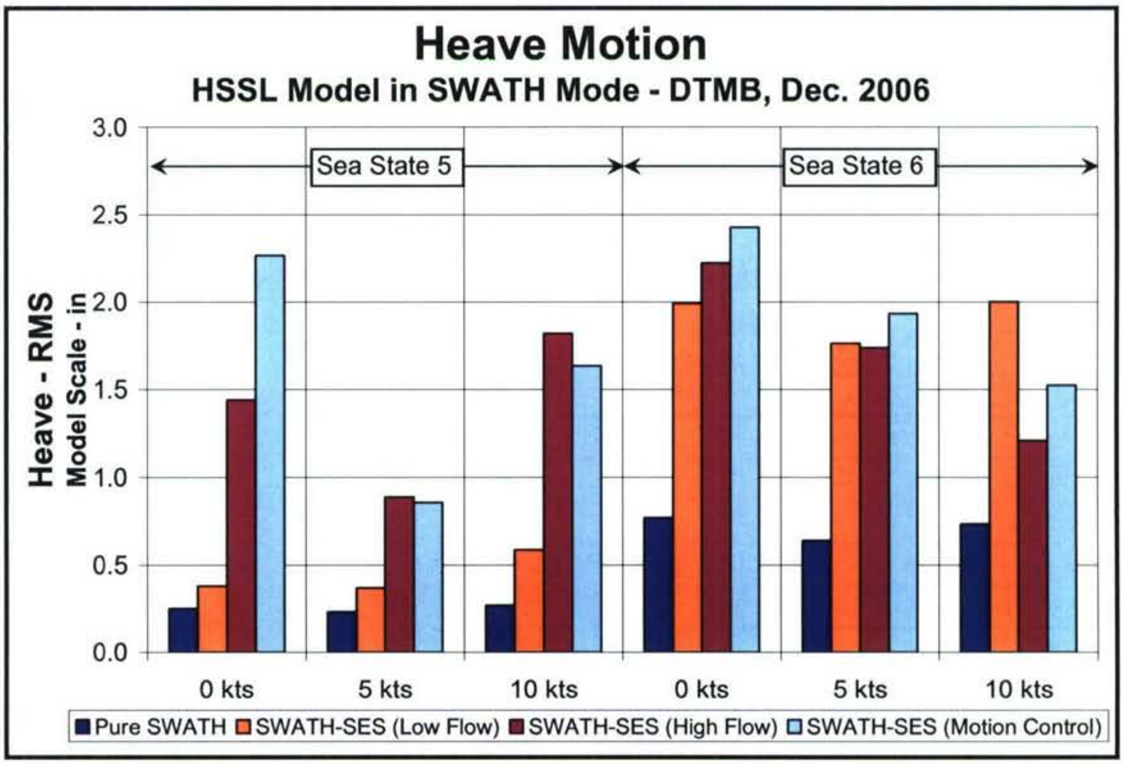


Figure 3-16 – Heave Motion RMS Values for HSSL Model in SWATH Mode

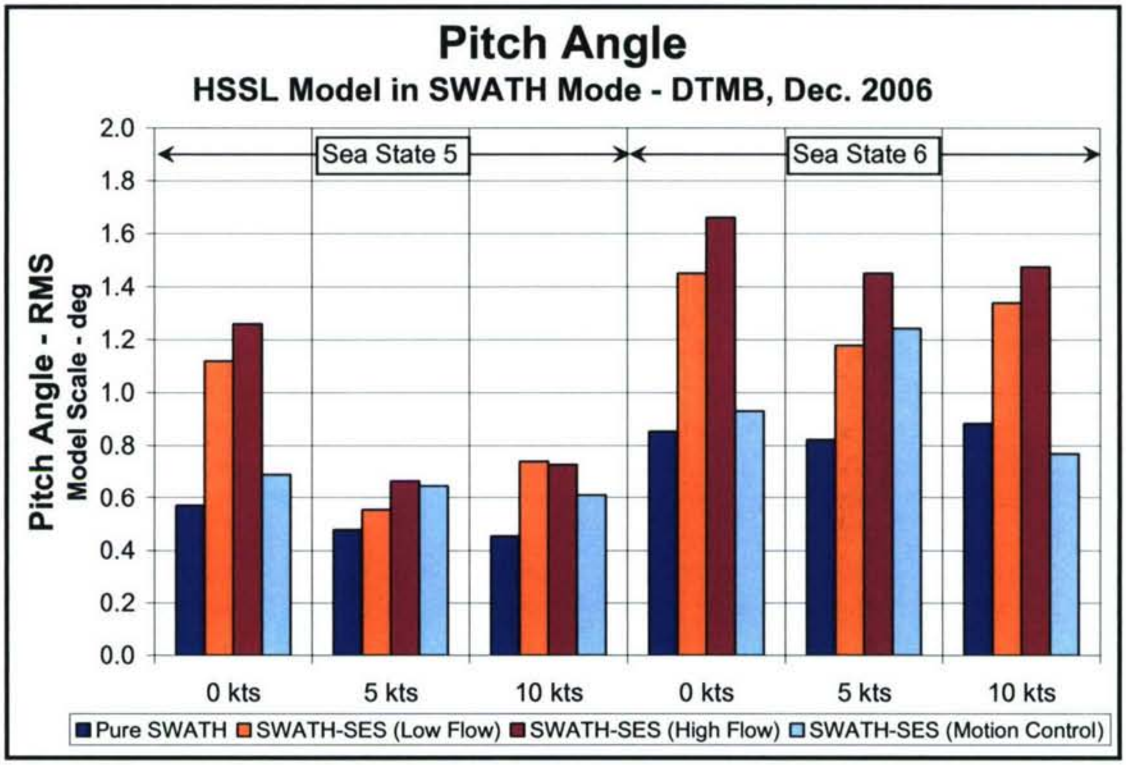


**Figure 3-17 – Pitch Angle RMS Values for HSSL Model in SWATH Mode**

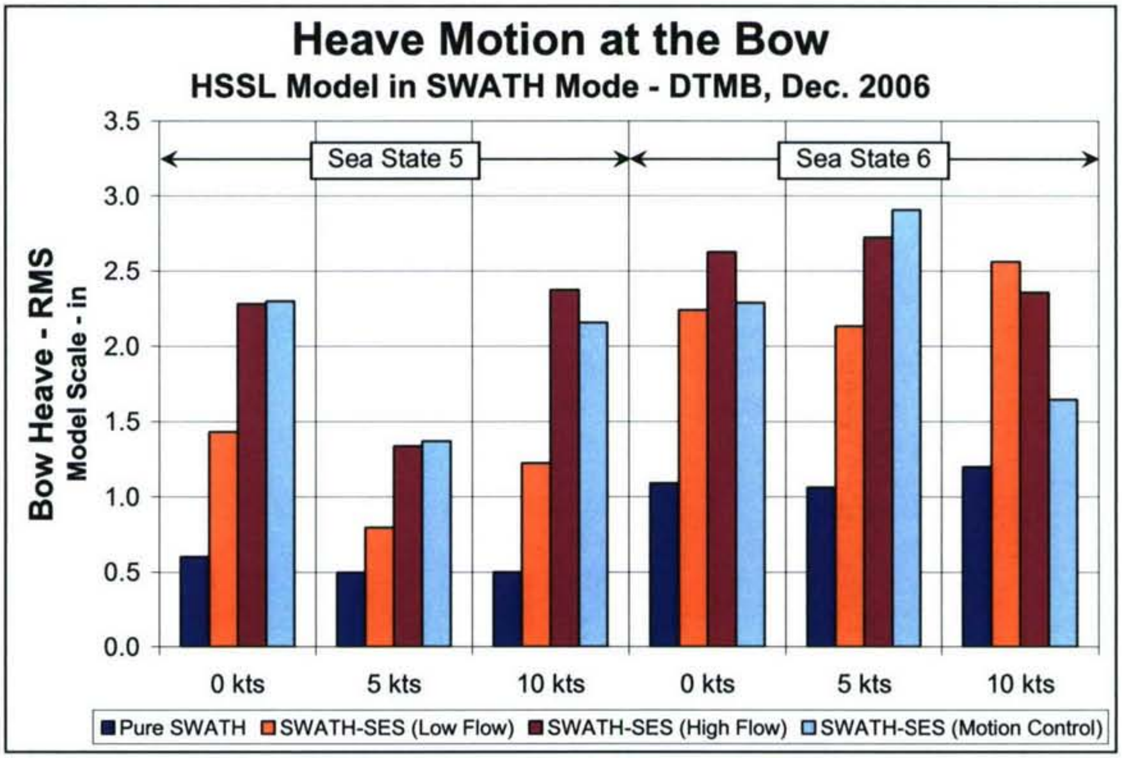


**Figure 3-18 – Bow Heave Motion RMS Values for HSSL Model in SWATH Mode**

## 3.6 Propulsion Machinery

### 3.6.1 Design Description

Large, high-speed ships will require significant amounts of installed power for propulsion and the fuel loads can be substantial when range goals are high. For a long-range, high-speed ship design application such as HSSL, minimizing overall ship drag has important benefits. Waterjets with flush inlets have extremely low drag impact on a vessel and will likely be the best form of propulsion. The HSSL application requires high speeds and long range, and will experience large ship weight variations due to fuel burn-off and changes in payload weight. This further makes waterjets the most logical propulsion choice since only a waterjet type system can perform efficiently over the very wide range of operating conditions that are anticipated.

High-speed ships favor long slender hullforms to minimize drag, and the use of multihulls will result in very high length-to-beam ratios for the individual hulls. Long slender hulls help minimize transom drag by keeping the transom area and width to a minimum. This sets up the situation where the size of the waterjets can drive the size of the transom region beyond desirable size limits in order to accommodate the waterjets, with a resulting negative impact on drag from a need to enlarge the transom. All current large commercial waterjets are of a mixed-flow arrangement where the waterjet unit grows in diameter to be 50 to 80 percent larger at its maximum than its inlet diameter. This is because the mixed-flow arrangement makes use of a radial component of flow velocity for part of its headrise. To recover the outward radial flow velocity component, the waterjet unit diameter must increase to accommodate the transition to the stator vanes that accomplish this recovery. The increased diameter has two drawbacks in that overall waterjet system weight, including the extra weight of entrained water, will increase as basically a function of the diameter cubed, and the increased diameter will require additional installation width. Increased installation width for the narrower hulls and transoms that are typical of high-speed ships is not desirable. Installation of multiple waterjet units is typically required by meaningfully large high-speed ships in order to absorb the large amounts of power required which must come from multiple large gas turbine engines. The number of waterjet units that can be installed in a transom without requiring drag-increasing modifications to the transom will favor waterjets with minimum installation width requirements.

The development of large-size axial-flow waterjets will benefit high-speed ships, as recognized by BLA more than 16 years ago. An axial-flow waterjet impeller does not depend on a radial component of flow velocity for headrise so that the maximum internal diameter of the axial waterjet is the same as its inlet diameter. The installation width of the axial waterjet will be only about 15 to 20 percent larger than its inlet diameter to allow for its transom mounting flange and access space between adjacent units. This allows more units to be installed in a given transom width than with present mixed-flow waterjet designs. The smaller size requirements of the axial-flow unit also reduces overall waterjet system weight by 15 to 30 percent compared to a comparable mixed-flow unit, which is most important for high-speed, weight-sensitive ships. By using advanced

computational fluid dynamics tools, it has been found that axial-flow impeller designs can meet necessary waterjet requirements with a single stage and that the hydraulic efficiency of an axial impeller design will be comparable to that of a mixed-flow design. Therefore, considerable interest and development is being focused on axial-flow waterjets because of the large weight savings potential with performance comparable to presently available units. Large axial-flow waterjets will now be a near-term reality and are of significant importance for the long-range, weight-sensitive applications such as HSSL. Our present HSSL design is based on using an axial-flow waterjet design which we have developed and model tested to verify performance so that it has known capabilities. Using non-dimensional head and flow coefficients for the axial waterjet allows it to be scaled to any speed or power application.

The waterjet propulsion arrangement that is presently developed for this HSSL application uses two axial waterjet units in each of the two hulls. Two powering cases are looked at for comparison. The first case has two 50 MW gas turbines driving each axial waterjet unit for a total of eight gas turbines driving the four same-size axial waterjet units. The second case uses two axial waterjets of different sizes on each demihull. On each hull, two 50 MW gas turbines are combined to drive one large axial waterjet unit while a single 50 MW gas turbine is used to drive a smaller axial waterjet unit.

### 3.6.2 Design Considerations

With waterjet propulsion, there are many choices and options to be made that can impact ship size, weight, and performance. The typical waterjet steering and reversing system is heavy and weighs about the same as the dry weight of the waterjet unit itself and upon which it is mounted. Steering and reversing gears should not necessarily be installed on all the waterjet units. With two waterjet units per sidehull, it is best to have the full steering and reversing on only one of the units on each side to save considerable weight. It would be best mounted on the smaller of the two waterjet units, if one is smaller, to further minimize weight. This leaves the second and larger waterjet unit on each side as primarily a booster unit mainly intended to operate at high speeds. Differential thrust can be used to supplement steering at high speeds, if necessary. In emergencies, cutting power to the booster waterjet units will quickly reduce ship speed to better utilize the single reversing unit per side.

Propulsive efficiency is an increasingly important design consideration as ship range requirements increase due to the growth in fuel load requirements that offset payload. The waterjet unit is mounted internally on the hull, which essentially eliminates any drag associated with the propulsor. Improved waterjet propulsive efficiency basically requires that the waterjet unit be made larger in diameter so that more mass flow can be pumped with a lower headrise. This reduces the exit jet velocity and thus lowers the jet kinetic energy losses. Waterjet size or diameter grows with an increase in the mass flow it is intended to pump. However, the weight of the waterjet unit and its entrained water are internal to the hull and must be accounted for in the weight balance. Waterjet system weight increases as approximately the cube of diameter, so that propulsive efficiency

improvements are gradually offset by the additional weight required for the waterjet system. There is a point reached with increasing waterjet diameter where the waterjet unit weight growth for each additional pound of thrust exceeds the design point lift-to-drag of the ship. Also, as mentioned earlier, the larger the waterjet units, the more difficult it is to fit them in the more slender hulls favored by high-speed ships.

Waterjet propulsive efficiency will benefit from the waterjet inlet ingesting portions of the lower momentum fluid from the hull boundary layer. The waterjet thrust is basically the difference between the momentum out minus the momentum into the waterjet unit. For the same flow rate and power, the boundary layer ingestion lowers the inlet momentum velocity at a slightly faster rate than the resulting outlet momentum velocity, so that there is an increasing gain in thrust with reducing inlet momentum velocity from the boundary layer ingestion which improves the propulsive efficiency. Lowering outlet momentum velocity also helps improve propulsive efficiency by reducing the kinetic energy losses in the jet. Boundary layer ingestion by the waterjet inlet can recover a good portion of the energy that the hull has transmitted to the water to form the hull boundary layer. Boundary layer formation on the hull represents friction drag that must be overcome by the propulsor. As such, boundary layer ingestion is not a design tool for improving propulsive efficiency, but uses the available hull boundary layer to benefit the propulsive efficiency in the overall accounting and waterjet considerations.

Cavitation is always a consideration in sizing and final selection of the waterjet units due to the damage and reduced unit life that cavitation will cause. The waterjet needs to be free of cavitation at operating conditions where it is expected to spend any significant amount of operating time. Cavitation under transient conditions, such as acceleration, is acceptable and does not affect performance as long as there is sufficient design margin to avoid cavitation breakdown. The waterjet unit size is essentially set by the minimum speed of the ship for which the unit must be able to operate for extended periods of time at full power compared to the design speed.

### 3.6.3 Waterjet Arrangements

To meet the predicted ship drag requirements, the waterjet propulsion arrangement developed, described herein and shown in Figure A-11 and Figure A-15 in Appendix A3, uses two waterjet propulsion units for each of the two hulls. HSSL notional performance goals will result in a ship of meaningful size but significant power to meet its high-speed goals. Two axial waterjet sizes were developed based on a single 50 MW gas turbine and a 100 MW waterjet driven by two 50 MW gas turbines. Figure 3-19 and Figure 3-20 show the optimization range and resulting performance for the 50 MW and 100 MW axial waterjets, respectively. The figures are based on using the nondimensional head and flow coefficients of an axial-flow waterjet design that we have developed and tested. The figures explore a range of impeller tip speeds to determine the waterjet sizing and performance based on the input design requirements and conditions listed at the top of the figure. These will be large high-power waterjet pumps, and the assumed hydraulic efficiency of 0.925 is reasonable for pumps of this size. Boundary layer ingestion is assumed at a realistic level with the inlet wake value of 0.058 indicating that the waterjet

inlet momentum velocity due to boundary layer ingestion is 5.8 percent below the ship speed. The waterjet was assumed to have its shaft centerline at the waterline for the optimizations since the present ship concept has a wide variation of possible submergences. Any submergence during operation would benefit cavitation margins. With increasing impeller tip speeds, the required impeller diameter and therefore system weight will decrease. However, the net thrust and propulsive efficiency are declining with increasing tip speed as is the cavitation margin indicated by the increasing Suction Specific Speed (Nsss). The tip speed of 148 feet per second was highlighted in both figures as the maximum tip speed likely for this application and was used for sizing the waterjet unit layouts. Waterjet propulsive efficiencies are indicated in the figure and should certainly be at least about 0.665 for the design assumptions that are used and are felt to be slightly conservative.

Figure 3-19 and Figure 3-20 give an understanding of the trade-offs and trends that are involved in the waterjet design selection. When the waterjet power is doubled from Figure 3-19 to Figure 3-20, it can be seen that the waterjet system weights in the right-hand columns increase by much more than double. It should also be noted that the weight of entrained water in the waterjet system far exceeds the dry pump weight and that the steering and reversing system (S/R) weight will be on the order of the waterjet system dry weight. Therefore, it is beneficial not to put steering and reversing on every waterjet unit.

Figure 3-21 and Figure 3-22 show the overall thrust performance with ship speed for different power levels based on installed waterjet system powers of 300 MW and 400 MW, respectively. The light ship and heavy ship predicted drags versus speed are also plotted on each figure to indicate the power requirements at off design point conditions. The 300 MW installed power case (six 50 MW gas turbines installed) of Figure 3-21 uses one 50 MW waterjet unit and one 100 MW waterjet unit in each of the two hulls. Figure 3-21 indicates that this is just enough installed power to bracket the desired 43-knot design operating speed utilizing full turbine power. Operation of these turbines at their 90-percent power rating would still allow ship speeds in the 41 to 42-knot range with the 300 MW of installed power. Figure 3-22 is based on 400 MW of installed power (eight 50 MW gas turbines installed) with two 100 MW waterjet units in each of the two hulls. For this power level case, the gas turbines only need to operate at about their 75-percent power level to bracket the desired 43-knot ship design speed. The 400 MW installed power case requires two additional 50 MW gas turbines and a larger waterjet unit in each hull compared to the 300 MW installed power case, but is presented for comparison purposes.

### 3.6.4 Recommendations for Future Study

The waterjet system sizing and performance was based on scaling an axial waterjet design based on its model test data and should be very representative of what can be achieved. Additional refinement of the design variables affecting the waterjet system sizing can further benefit the waterjet system and its impact on the ship. Further hull optimization and evaluation of future ship model towing-tank data may reduce the

predicted ship drag and will need to be reviewed. The use of two 50 MW waterjets would save significant installed weight compared to using a 100 MW waterjet instead. The problem is finding transom region space sufficient to install the two smaller diameter waterjets which, when placed adjacent to each other, have a greater installed dimension in that one direction than that of the single larger waterjet.

**For SAIC - Original design point Phi & Psi**

| | PUMP : Fixed | | INPUTS : | | | | | | | Calculated or Fixed Values : | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utip (fps) Increment | Psi Head Coef | Phi Flow Coef | Vdesign knots | Inlet Wake | Pump Effic | Pump Depth-ft | Nozzle Depth-ft | Power HP | Trans Eff | WJ Shaft MW | Patm feeet | Pvapor feeet | Lamda Hub/Tip | Sea Water lbm/ft^3 |
| 1.00 | 0.464 | 0.375 | 43 | 0.058 | 0.925 | 0 | 0 | 67050 | 1.000 | 50 MW | 33.1 | 0.81 | 0.3 | 64.04 |

| Tip Speed fps | Vax fps | Head ft | Flow cfs | Diameter inch | RPM | IVR Ratio | Ram Recovery | NPSH ft | Nsss | Pnoz ft | Vjet fps | JVR | Nozzle Ratio | Net Thrust lbf | Propulsive Efficiency | Dry Wt Lton | Water Wt Lton | Wet Wt Lton | S/R Wt Lton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140.00 | 52.50 | 141.33 | 3768.88 | 120.27 | 266.79 | 0.7356 | 0.8320 | 92.73 | 11612 | 201.77 | 113.94 | 1.570 | 0.648 | 341,910 | 0.6729 | 49.2 | 117.5 | 166.6 | 45.1 |
| 141.00 | 52.88 | 143.36 | 3715.62 | 118.99 | 271.58 | 0.7408 | 0.8328 | 92.78 | 11731 | 203.85 | 114.53 | 1.578 | 0.648 | 341,422 | 0.6719 | 47.7 | 113.8 | 161.5 | 43.7 |
| 142.00 | 53.25 | 145.40 | 3663.47 | 117.73 | 276.42 | 0.7461 | 0.8337 | 92.84 | 11851 | 205.95 | 115.12 | 1.586 | 0.649 | 340,920 | 0.6709 | 46.3 | 110.2 | 156.6 | 42.4 |
| 143.00 | 53.63 | 147.45 | 3612.41 | 116.50 | 281.31 | 0.7513 | 0.8345 | 92.90 | 11970 | 208.07 | 115.71 | 1.594 | 0.649 | 340,405 | 0.6699 | 45.0 | 106.8 | 151.8 | 41.2 |
| 144.00 | 54.00 | 149.52 | 3562.41 | 115.29 | 286.26 | 0.7566 | 0.8353 | 92.96 | 12091 | 210.19 | 116.30 | 1.602 | 0.650 | 339,876 | 0.6689 | 43.7 | 103.5 | 147.3 | 40.0 |
| 145.00 | 54.38 | 151.61 | 3513.44 | 114.10 | 291.25 | 0.7619 | 0.8360 | 93.02 | 12211 | 212.33 | 116.89 | 1.611 | 0.651 | 339,336 | 0.6678 | 42.5 | 100.4 | 142.8 | 38.8 |
| 146.00 | 54.75 | 153.71 | 3465.48 | 112.93 | 296.30 | 0.7671 | 0.8368 | 93.07 | 12332 | 214.49 | 117.48 | 1.619 | 0.651 | 338,785 | 0.6667 | 41.3 | 97.3 | 138.6 | 37.7 |
| 147.00 | 55.13 | 155.82 | 3418.49 | 111.78 | 301.40 | 0.7724 | 0.8376 | 93.13 | 12453 | 216.66 | 118.07 | 1.627 | 0.652 | 338,222 | 0.6656 | 40.1 | 94.4 | 134.5 | 36.6 |
| 148.00 | 55.50 | 157.95 | 3372.45 | 110.65 | 306.55 | 0.7776 | 0.8383 | 93.18 | 12575 | 218.84 | 118.67 | 1.635 | 0.652 | 337,649 | 0.6645 | 39.0 | 91.6 | 130.6 | 35.6 |
| 149.00 | 55.88 | 160.09 | 3327.33 | 109.54 | 311.76 | 0.7829 | 0.8391 | 93.24 | 12697 | 221.04 | 119.26 | 1.643 | 0.653 | 337,066 | 0.6634 | 37.9 | 88.9 | 126.8 | 34.6 |
| 150.00 | 56.25 | 162.24 | 3283.12 | 108.44 | 317.01 | 0.7881 | 0.8398 | 93.29 | 12820 | 223.25 | 119.86 | 1.651 | 0.654 | 336,473 | 0.6622 | 36.9 | 86.2 | 123.1 | 33.6 |
| 151.00 | 56.63 | 164.41 | 3239.78 | 107.37 | 322.32 | 0.7934 | 0.8406 | 93.35 | 12942 | 225.47 | 120.45 | 1.660 | 0.654 | 335,872 | 0.6610 | 35.9 | 83.7 | 119.6 | 32.7 |
| 152.00 | 57.00 | 166.60 | 3197.29 | 106.31 | 327.69 | 0.7986 | 0.8413 | 93.40 | 13066 | 227.71 | 121.05 | 1.668 | 0.655 | 335,261 | 0.6598 | 34.9 | 81.3 | 116.2 | 31.8 |
| 153.00 | 57.38 | 168.80 | 3155.63 | 105.27 | 333.10 | 0.8039 | 0.8420 | 93.45 | 13189 | 229.96 | 121.64 | 1.676 | 0.655 | 334,643 | 0.6586 | 33.9 | 78.9 | 112.9 | 30.9 |
| 154.00 | 57.75 | 171.01 | 3114.78 | 104.24 | 338.57 | 0.8091 | 0.8427 | 93.50 | 13313 | 232.22 | 122.24 | 1.684 | 0.656 | 334,016 | 0.6574 | 33.0 | 76.7 | 109.7 | 30.1 |
| 155.00 | 58.13 | 173.24 | 3074.72 | 103.24 | 344.09 | 0.8144 | 0.8434 | 93.55 | 13438 | 234.50 | 122.84 | 1.693 | 0.656 | 333,383 | 0.6561 | 32.1 | 74.5 | 106.6 | 29.2 |
| 156.00 | 58.50 | 175.48 | 3035.43 | 102.25 | 349.67 | 0.8197 | 0.8441 | 93.60 | 13562 | 236.80 | 123.44 | 1.701 | 0.657 | 332,742 | 0.6548 | 31.3 | 72.3 | 103.6 | 28.4 |
| 157.00 | 58.88 | 177.74 | 2996.88 | 101.27 | 355.30 | 0.8249 | 0.8448 | 93.65 | 13688 | 239.10 | 124.04 | 1.709 | 0.657 | 332,094 | 0.6536 | 30.5 | 70.3 | 100.8 | 27.7 |
| 158.00 | 59.25 | 180.01 | 2959.07 | 100.31 | 360.99 | 0.8302 | 0.8455 | 93.70 | 13813 | 241.42 | 124.64 | 1.717 | 0.658 | 331,441 | 0.6523 | 29.7 | 68.3 | 98.0 | 27.0 |
| 159.00 | 59.63 | 182.30 | 2921.96 | 99.37 | 366.73 | 0.8354 | 0.8462 | 93.75 | 13939 | 243.76 | 125.24 | 1.726 | 0.658 | 330,781 | 0.6510 | 28.9 | 66.4 | 95.3 | 26.2 |
| 160.00 | 60.00 | 184.60 | 2885.55 | 98.44 | 372.52 | 0.8407 | 0.8468 | 93.80 | 14065 | 246.11 | 125.84 | 1.734 | 0.659 | 330,115 | 0.6497 | 28.2 | 64.6 | 92.7 | 25.6 |
| 161.00 | 60.38 | 186.91 | 2849.82 | 97.52 | 378.37 | 0.8459 | 0.8475 | 93.85 | 14192 | 248.47 | 126.45 | 1.742 | 0.659 | 329,445 | 0.6484 | 27.4 | 62.8 | 90.2 | 24.9 |
| 162.00 | 60.75 | 189.24 | 2814.74 | 96.62 | 384.27 | 0.8512 | 0.8481 | 93.89 | 14319 | 250.84 | 127.05 | 1.751 | 0.660 | 328,769 | 0.6470 | 26.7 | 61.1 | 87.8 | 24.2 |

**For SAIC - Single Design Point Case**

| Utip fps | Vax fps | Head ft | Flow cfs | Diameter inch | RPM | IVR Ratio | Ram Recovery | NPSH ft | Nsss | Pnoz ft | Vjet fps | JVR | HP check | Net Thrust lbf | Propulsive Efficiency | Dry Wt Lton | Water Wt Lton | Wet Wt Lton | S/R Wt Lton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148.00 | 55.50 | 157.95 | 3372.45 | 110.65 | 306.55 | 0.7776 | 0.8383 | 93.18 | 12575 | 218.84 | 118.67 | 1.635 | 67050.0 | 337,649 | 0.6645 | 39.0 | 91.6 | 130.6 | 35.6 |
| *For SAIC - Delta Change in WJ System Weight per Additional lbf of Thrust ( Wet Wt, with S/R ) -->* | | | | | | | | | | | | | | | Pump Weight to Thrust Delta> | | | 15.00 | 18.96 |
| 148.01 | 55.50 | 157.97 | 3371.99 | 110.64 | 306.60 | 0.7777 | 0.8384 | 93.18 | 12576 | 218.86 | 118.67 | 1.635 | 67050.0 | 337,643 | 0.6645 | 38.98 | 91.56 | 130.53 | 35.57 |
| 147.99 | 55.50 | 157.92 | 3372.91 | 110.66 | 306.50 | 0.7776 | 0.8383 | 93.18 | 12574 | 218.82 | 118.66 | 1.635 | 67050.0 | 337,655 | 0.6645 | 39.00 | 91.61 | 130.61 | 35.59 |

Figure 3-19 – Waterjet Sizing Optimization for a 50 MW Axial Waterjet

## For SAIC - Original design point Phi & Psi

| | PUMP : Fixed | | INPUTS : | | | | | | | Calculated or Fixed Values : | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utip (fps) Increment | Psi Head Coef | Phi Flow Coef | Vdesign knots | Inlet Wake | Pump Effic | Pump Depth-ft | Nozzle Depth-ft | Power HP | Trans Eff | WJ Shaft MW | Patm feeet | Pvapor feeet | Lamda Hub/Tip | Sea Water lbm/ft^3 |
| 1.00 | 0.464 | 0.375 | 43 | 0.058 | 0.925 | 0 | 0 | 134100 | 1.000 | 100 MW | 33.1 | 0.81 | 0.3 | 64.04 |

| Tip Speed fps | Vax fps | Head ft | Flow cfs | Diameter inch | RPM | IVR Ratio | Ram Recovery | NPSH ft | Nsss | Pnoz ft | Vjet fps | JVR | Nozzle Ratio | Net Thrust lbf | Propulsive Efficiency | Dry Wt Lton | Water Wt Lton | Wet Wt Lton | S/R Wt Lton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140.00 | 52.50 | 141.33 | 7537.77 | 170.08 | 188.65 | 0.7356 | 0.8320 | 92.73 | 11612 | 201.77 | 113.94 | 1.570 | 0.648 | 683,821 | 0.6729 | 129.0 | 330.4 | 459.4 | 121.0 |
| 141.00 | 52.88 | 143.36 | 7431.23 | 168.28 | 192.04 | 0.7408 | 0.8328 | 92.78 | 11731 | 203.85 | 114.53 | 1.578 | 0.648 | 682,844 | 0.6719 | 125.2 | 320.0 | 445.2 | 117.3 |
| 142.00 | 53.25 | 145.40 | 7326.93 | 166.50 | 195.46 | 0.7461 | 0.8337 | 92.84 | 11851 | 205.95 | 115.12 | 1.586 | 0.649 | 681,840 | 0.6709 | 121.6 | 310.1 | 431.6 | 113.8 |
| 143.00 | 53.63 | 147.45 | 7224.82 | 164.76 | 198.92 | 0.7513 | 0.8345 | 92.90 | 11970 | 208.07 | 115.71 | 1.594 | 0.649 | 680,809 | 0.6699 | 118.1 | 300.5 | 418.5 | 110.5 |
| 144.00 | 54.00 | 149.52 | 7124.82 | 163.04 | 202.41 | 0.7566 | 0.8353 | 92.96 | 12091 | 210.19 | 116.30 | 1.602 | 0.650 | 679,753 | 0.6689 | 114.7 | 291.3 | 405.9 | 107.2 |
| 145.00 | 54.38 | 151.61 | 7026.89 | 161.36 | 205.95 | 0.7619 | 0.8360 | 93.02 | 12211 | 212.33 | 116.89 | 1.611 | 0.651 | 678,673 | 0.6678 | 111.4 | 282.4 | 393.8 | 104.1 |
| 146.00 | 54.75 | 153.71 | 6930.96 | 159.71 | 209.52 | 0.7671 | 0.8368 | 93.07 | 12332 | 214.49 | 117.48 | 1.619 | 0.651 | 677,569 | 0.6667 | 108.3 | 273.8 | 382.1 | 101.1 |
| 147.00 | 55.13 | 155.82 | 6836.98 | 158.08 | 213.12 | 0.7724 | 0.8376 | 93.13 | 12453 | 216.66 | 118.07 | 1.627 | 0.652 | 676,444 | 0.6656 | 105.2 | 265.6 | 370.8 | 98.2 |
| 148.00 | 55.50 | 157.95 | 6744.90 | 156.48 | 216.76 | 0.7776 | 0.8383 | 93.18 | 12575 | 218.84 | 118.67 | 1.635 | 0.652 | 675,298 | 0.6645 | 102.3 | 257.7 | 359.9 | 95.3 |
| 149.00 | 55.88 | 160.09 | 6654.67 | 154.91 | 220.44 | 0.7829 | 0.8391 | 93.24 | 12697 | 221.04 | 119.26 | 1.643 | 0.653 | 674,132 | 0.6634 | 99.4 | 250.0 | 349.4 | 92.6 |
| 150.00 | 56.25 | 162.24 | 6566.24 | 153.36 | 224.16 | 0.7881 | 0.8398 | 93.29 | 12820 | 223.25 | 119.86 | 1.651 | 0.654 | 672,946 | 0.6622 | 96.7 | 242.6 | 339.3 | 90.0 |
| 151.00 | 56.63 | 164.41 | 6479.55 | 151.84 | 227.92 | 0.7934 | 0.8406 | 93.35 | 12942 | 225.47 | 120.45 | 1.660 | 0.654 | 671,743 | 0.6610 | 94.1 | 235.5 | 329.6 | 87.5 |
| 152.00 | 57.00 | 166.60 | 6394.58 | 150.34 | 231.71 | 0.7986 | 0.8413 | 93.40 | 13066 | 227.71 | 121.05 | 1.668 | 0.655 | 670,522 | 0.6598 | 91.5 | 228.7 | 320.2 | 85.1 |
| 153.00 | 57.38 | 168.80 | 6311.26 | 148.87 | 235.54 | 0.8039 | 0.8420 | 93.45 | 13189 | 229.96 | 121.64 | 1.676 | 0.655 | 669,285 | 0.6586 | 89.0 | 222.1 | 311.1 | 82.7 |
| 154.00 | 57.75 | 171.01 | 6229.56 | 147.42 | 239.41 | 0.8091 | 0.8427 | 93.50 | 13313 | 232.22 | 122.24 | 1.684 | 0.656 | 668,033 | 0.6574 | 86.6 | 215.7 | 302.3 | 80.4 |
| 155.00 | 58.13 | 173.24 | 6149.44 | 146.00 | 243.31 | 0.8144 | 0.8434 | 93.55 | 13438 | 234.50 | 122.84 | 1.693 | 0.656 | 666,765 | 0.6561 | 84.3 | 209.5 | 293.8 | 78.2 |
| 156.00 | 58.50 | 175.48 | 6070.85 | 144.60 | 247.25 | 0.8197 | 0.8441 | 93.60 | 13562 | 236.80 | 123.44 | 1.701 | 0.657 | 665,484 | 0.6548 | 82.1 | 203.6 | 285.7 | 76.1 |
| 157.00 | 58.88 | 177.74 | 5993.76 | 143.22 | 251.24 | 0.8249 | 0.8448 | 93.65 | 13688 | 239.10 | 124.04 | 1.709 | 0.657 | 664,189 | 0.6536 | 79.9 | 197.8 | 277.8 | 74.1 |
| 158.00 | 59.25 | 180.01 | 5918.13 | 141.86 | 255.26 | 0.8302 | 0.8455 | 93.70 | 13813 | 241.42 | 124.64 | 1.717 | 0.658 | 662,881 | 0.6523 | 77.8 | 192.3 | 270.1 | 72.1 |
| 159.00 | 59.63 | 182.30 | 5843.93 | 140.53 | 259.31 | 0.8354 | 0.8462 | 93.75 | 13939 | 243.76 | 125.24 | 1.726 | 0.658 | 661,562 | 0.6510 | 75.8 | 186.9 | 262.8 | 70.2 |
| 160.00 | 60.00 | 184.60 | 5771.11 | 139.21 | 263.41 | 0.8407 | 0.8468 | 93.80 | 14065 | 246.11 | 125.84 | 1.734 | 0.659 | 660,231 | 0.6497 | 73.9 | 181.8 | 255.6 | 68.3 |
| 161.00 | 60.38 | 186.91 | 5699.64 | 137.91 | 267.55 | 0.8459 | 0.8475 | 93.85 | 14192 | 248.47 | 126.45 | 1.742 | 0.659 | 658,889 | 0.6484 | 72.0 | 176.8 | 248.7 | 66.5 |
| 162.00 | 60.75 | 189.24 | 5629.49 | 136.64 | 271.72 | 0.8512 | 0.8481 | 93.89 | 14319 | 250.84 | 127.05 | 1.751 | 0.660 | 657,537 | 0.6470 | 70.1 | 171.9 | 242.1 | 64.8 |

## For SAIC - Single Design Point Case

| Utip fps | Vax fps | Head ft | Flow cfs | Diameter inch | RPM | IVR Ratio | Ram Recovery | NPSH ft | Nsss | Pnoz ft | Vjet fps | JVR | HP check | Net Thrust lbf | Propulsive Efficiency | Dry Wt Lton | Water Wt Lton | Wet Wt Lton | S/R Wt Lton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148.00 | 55.50 | 157.95 | 6744.90 | 156.48 | 216.76 | 0.7776 | 0.8383 | 93.18 | 12575 | 218.84 | 118.67 | 1.635 | 134100.0 | 675,298 | 0.6645 | 102.3 | 257.7 | 359.9 | 95.3 |

**For SAIC - Delta Change in WJ System Weight per Additional lbf of Thrust ( Wet Wt, with S/R ) -->** Pump Weight to Thrust Delta> 20.68 26.02

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148.01 | 55.50 | 157.97 | 6743.99 | 156.46 | 216.80 | 0.7777 | 0.8384 | 93.18 | 12576 | 218.86 | 118.67 | 1.635 | 134100.0 | 675,286 | 0.6645 | 102.25 | 257.57 | 359.82 | 95.32 |
| 147.99 | 55.50 | 157.92 | 6745.81 | 156.50 | 216.73 | 0.7776 | 0.8383 | 93.18 | 12574 | 218.82 | 118.66 | 1.635 | 134100.0 | 675,309 | 0.6645 | 102.30 | 257.73 | 360.03 | 95.37 |

Figure 3-20 – Waterjet Sizing Optimization for a 100 MW Axial Waterjet

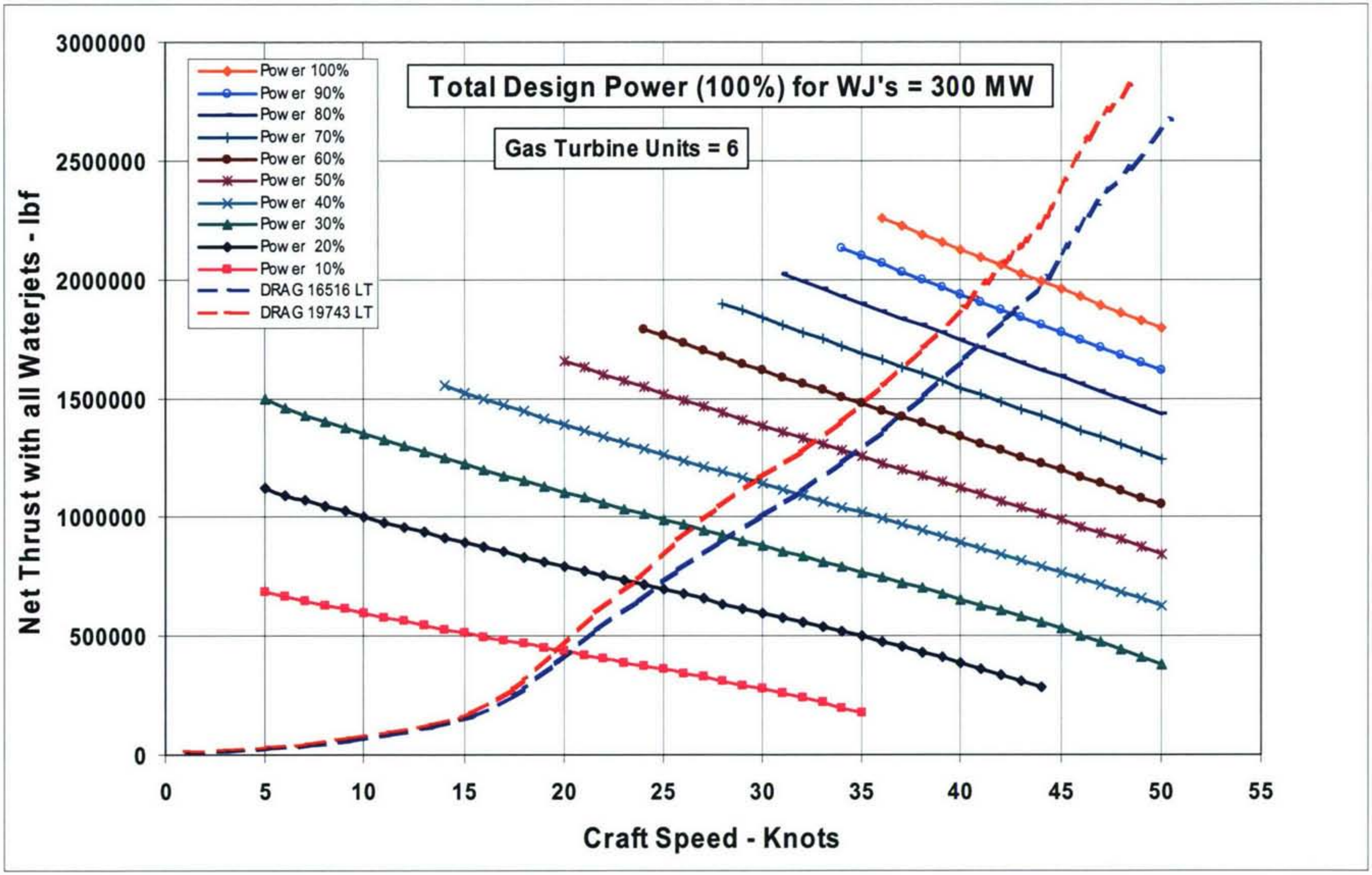


Figure 3-21 – Total Waterjet Thrust Performance with 300 MW Installed Power

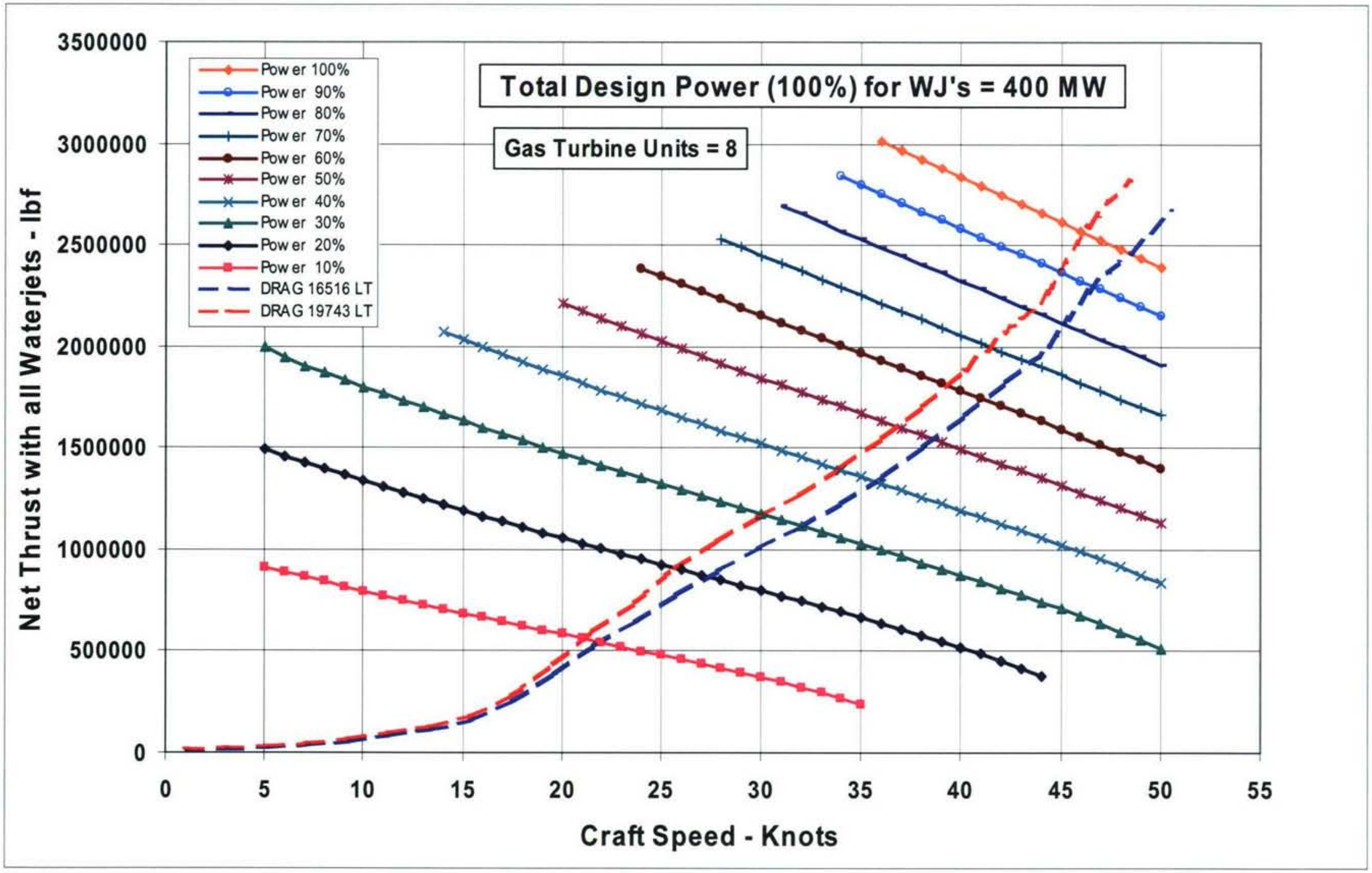


Figure 3-22 – Total Waterjet Thrust Performance with 400 MW Installed Power

## 3.7 Electric Plant

### 3.7.1 Design Description

The concept, the architecture for which is illustrated in Figure 3-23, calls for an Integrated Electric Power System, or IPS, a design whereby the electric drive propulsion system and the ship's service electrical system are powered from electrical sources in such a way that power can be distributed between them, on demand, according to the current operational situation. The key design element of integrated power and electric drive is a single-source generator for the requirements of all the ship's power needs, including propulsion. Through flexible distribution and switching architecture, the common electrical bus will supply electrical power to both non-propulsion and propulsion electrical loads and redistribute power as necessary. For propulsion, electrical power from the bus is sent to a motor drive, where the voltage and frequency of the electrical energy are modified to operate the propulsion motor at the desired speed. The propulsion motor converts the electrical energy delivered by the motor drive into mechanical energy to rotate the shaft of the waterjet propulsor.

The Electric Drive propulsion system developed for this design uses three 50 MW High Temperature Superconducting (HTS) electric motors in each demihull, two of which, via a combining gear, drive a boost waterjet and the third drives a steering and reversing waterjet. The IPS also provides sufficient power to supply the motors and fans of the SES lift air supply system, the other major power user, when the ship is operating at reduced speeds (10 knots and below) in either the SES Shallow Draft Mode or the SWATH Mode with SES activated for motion control.

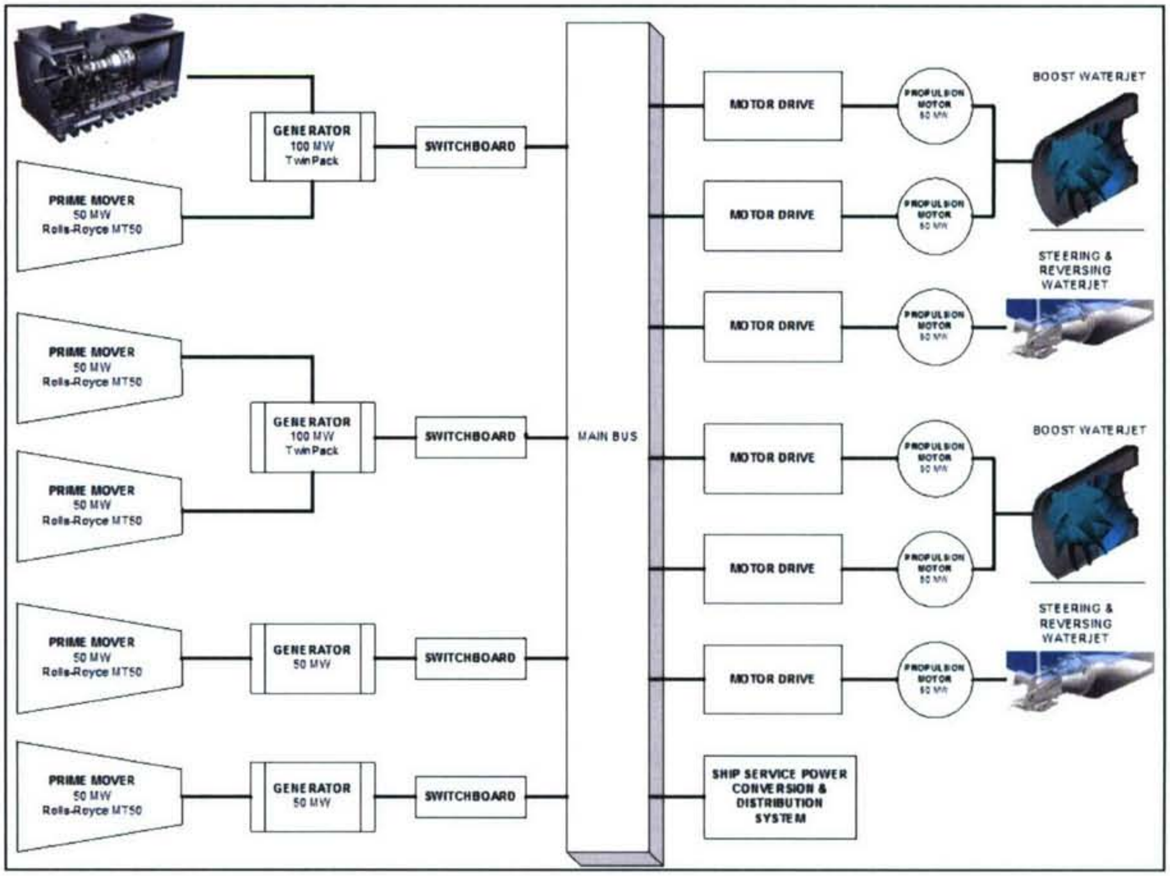


**Figure 3-23 – Integrated Power System**

## 3.7.2 Design Considerations

The design effort initially considered a conventional mechanical drive propulsion system. However, it soon became evident that, given the fuel and ballast requirements associated with the ship's mission, there was not sufficient volume in the demihulls to accommodate the prime movers and their associated shafting and gearboxes. Electric drive technology represented the only viable alternative, with the added benefit of being able to make use of the substantial amount of total installed power, driven by the 43-knot speed case, to provide power to other ship systems when this hybrid ship is operating in its other modes. Having cables, instead of shafting, connect the gas turbines to the propulsion motors provided architectural flexibility for the designer to make space available for payloads and improve construction and maintenance. Being able to locate the prime movers and generators (Generator Sets) to areas where they did not impose on other large volume spaces, specifically cargo holds, permitted unobstructed areas required in order to effectively and efficiently load and unload vehicles.

Since payload delivery/transfer is a critical capability of this ship, in addition to developing the power requirements for the SES Lift Air Supply system, the design effort also looked at the regulatory requirements for providing sufficient air volume exchange per hour for the vehicle cargo holds. Based on calculations performed using the imposed

constraints, notional ventilation system power requirements were derived from similar systems installed on the T-AKE class Navy vessel. Again, having a generous amount of installed power that can be put on the common electrical bus during the onload and offload of vehicle cargo, when high-speed propulsion is not an operational requirement, gives the commanding officer flexibility in how this energy is distributed to suit the range of cargo operations both in port and at sea.

### 3.7.3 Recommendations for Future Study

ComPASS™ performs an electrical loads analysis for various modes of ship operation and arrives at an estimated SWBS Group-3 weight, volume and cost. However, the specific design requirements of this integrated electric power system and related ship service distribution system is unique and should be developed further. This would include a ComPASS™ independent analysis of the predicted electrical loads of the ship, during its different operational modes, as the total ship system design matures. The design load plus future growth allowances should be considered in more detail to determine the required capacity of the proposed generating plants.

## 3.8 Auxiliary Systems, C4I, and Outfit & Furnishings

### 3.8.1 Design Description

Auxiliary systems and outfit & furnishings are identified, as necessary, to support mission and operational requirements. The concept design of required systems has been developed through a series of system requirements analyses and subsystem design solution studies that are intended to yield systems that have minimum ship acquisition and life-cycle cost impact. A number of the more prominent Auxiliary systems, for instance the SES Cushion Lift-Air Supply system and the Cargo Hold Ventilation system, have undergone a series of cursory trade-off studies. These resulted in these systems being sized and arranged such that their associated electric loads have been accounted for.

The set of calculations performed to size the cargo hold ventilation system to enable selection from a set of T-AKE derived fans are included in the supporting calculation section in Table 3-10.

The C4I suite is envisioned to be similar to that of the Navy's High Speed Vessel (HSV-X1), which includes the following items:

- Global Command & Control System (GCCS, GCCS-M, GCCS-A)
- Theater Battle Management Core Systems (TBMCS)
- USA ENRPS (Mobile Battle System – All Source Analysis System (ASAS), AFTDS Differential Signal Adapter

- Joint Service Imagery Processing System – Navy (JSIPS-N)
- Java Cryptography Architecture (JCA)
- Tactical Related Applications(TRAP) Data Dissemination System (TDDS)/ Tactical Information Broadcast Service (TIBS)
- Global Broadcasting Service (GBS)
- Phone Service through Teleport
- 8 Simultaneous Radio/Types (4 Tactical)
- Long Haul TCP/IP/ATM WAN with a Bandwidth of up to 27 Mbps
- Windows LiveMeeting Collaboration Software Suite
- Video Teleconferencing (VTC)
- Large Screen Video Display of any installed applications
- Microsoft Office Software Suite

All related radars/sensors are arranged in an Advanced Enclosed Mast/Sensor system similar in design to the prototype fitted on the USS Radford and a variation of which is currently being deployed on the LPD-17 class.

### 3.8.2 SES Cushion Lift-Air Supply System Design Considerations

The ship is powered by gas turbines within an Integrated Power System (IPS) having an electric power generation and distribution system which supplies power to all onboard electrical systems, including the propulsion and lift-air supply system. This allows significant flexibility of arrangement, as illustrated in Figure 3-23.

The lift-air supply system consists, therefore, of drive motors, fans, bearings, air inlets, and air distribution ducting to feed air to the SES cushion and transverse flexible seals. The flexible fabric seals (Figure A-3 in Appendix A2) are located at the forward and aft ends of the ship, spanning between the demihulls, to help contain the air cushion and allow the vessel to operate as an SES with the cushion supporting at least 30% of the vessel's total weight. Thus, the aerostatic lift generated by the cushion of pressurized air reduces the hydrostatic displacement and, therefore, provides a significant reduction in demihull draft to allow shallow-draft operation in austere ports around the world.

The SES cushion is also used with the vessel in the SWATH mode. This is done to provide control of ship motion in heave and pitch. Motion control is achieved by having a third transverse flexible seal amidships to create a two-compartment cushion with the air pressure in each compartment, forward and aft, actively controlled to provide not only

heave control but also pitch control. This is accomplished by having the air supplied separately to each compartment, fore and aft, using actively controlled variable geometry air-supply fans. With the 1/55$^{th}$-scale model tested at DTMB Carderock in December of 2006, cushion air flow and pressure control was achieved by having actively controlled vent valves in the model's wet deck to vent cushion air and thus control cushion pressure in each compartment. During the USN 3KSES program in the 1970's, it was shown that controlling the air supply with fan inlet guide vanes was a much more effective way of controlling cushion pressure than to vent the air cushion using louvers in the wet deck. The model tests conducted in December 2006 were to demonstrate the feasibility of combined heave and pitch control, which had never been attempted before. For these tests, it was much less expensive to have off-the-shelf fans and vents in the cushion compared to supplying a set of custom made fans with controllable inlet guide vanes.

Thus, the full-scale HSSL vessel has eight sets of single-width/single-inlet (SWSI) fans. Moving forward from the aft end of the ship, there are two sets, one each side, to provide air flow and boost pressure to feed the aft triple load stern seal. Air is taken from the cushion and boosted in pressure by 1% to 5% depending upon operating conditions. These stern seal fans, shown in profile view in Figure A-10 and in plan view in Figure A-14 in Appendix A3, do not have controllable inlet guide vanes for ship motion control since adequate flow and stern seal pressure changes to meet changing sea conditions can be controlled by changing fan rotational speed. Moving forward to amidships are six fan sets, with two on each side powered by the same shaft, but split so that one fan feeds air forward and one aft of the amidships divider on each side. The divider then has air supplied by one SISD fan on each side, delivering very little flow and on the order of a 30% increase in pressure, to give some rigidity to the flexible seal to allow it to sustain an acceptable pressure differential forward and aft in the cushion without the seal collapsing.

Utilizing the CDIM-SDD Design Synthesis Model (SDSM) for SES, an estimate of total cushion flow rate required was made assuming that the maximum demand for air flow without ride control would be for operation at relatively low speed in low sea state when on full cushion to achieve shallow draft operation. At full load, this total cushion flow rate was estimated to be 12,500 cubic feet per second (CFS) with a cushion pressure of 600 pounds per square feet (PSF).

In the SWATH mode, however, operation is required in heavy seas, but at no more than 10 knots. In this condition, with ride control active, the required flow rate for the cushion was estimated to be 33,000 CFS (2.6 times the flow for essentially calm water) with a cushion pressure of only 400 PSF.

To produce the relatively high flow and pressure to meet these two operating conditions, fans capable of operating at relatively high tip speeds are required. In order to minimize blade bending stresses, it was then necessary to consider using a centrifugal fan with blades having a short span, such as the Rotating Diffuser (RD) fans that were examined and determined to be suitable for the large SES being explored by the USN more than 30 years ago. Figure 3-24 from Reference 1 is a general arrangement drawing of a RD Fan first produced by the NEU Blower Factory in Lille France who built the big forced draft blowers for the steam plant on the liner the Isle de France. They also built huge fans for

big steel foundries and chemical plants. Bill White at NAVSEA had tracked them down when challenged by those who said that no one had ever built large fans that could lift large SES or ACV's. Fans of this design ended up being considered for use on the USN 3KSES. After the demise of the 3KSES program, a set was tested on the SES 200. They worked impressively well for a few months until they started to have corrosion problems, causing serious vibrations. They were built out of mild steel instead of stainless because of limited funds.

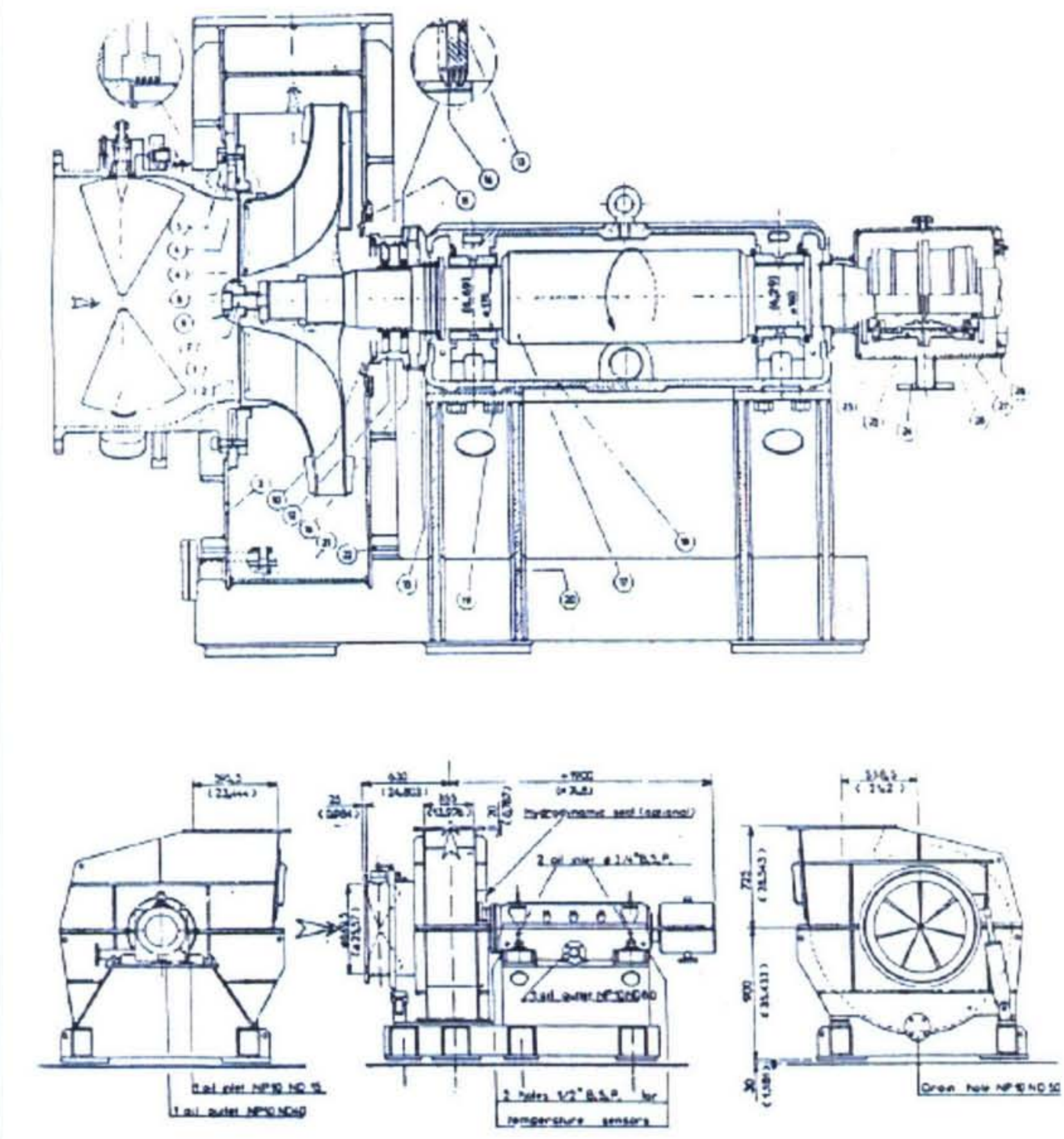

Figure 21: General Arrangement Drawing of Neuair Blower RD 92-.55-1.09

**Figure 3-24 – Drawing of Typical NEU RD-Fan with Adjustable Inlet Guide Vanes**

Figure 3-25 from Reference 1 illustrates the high pressures and flows that can be delivered by RD Fans that were produced by NEU more than 40 years ago.

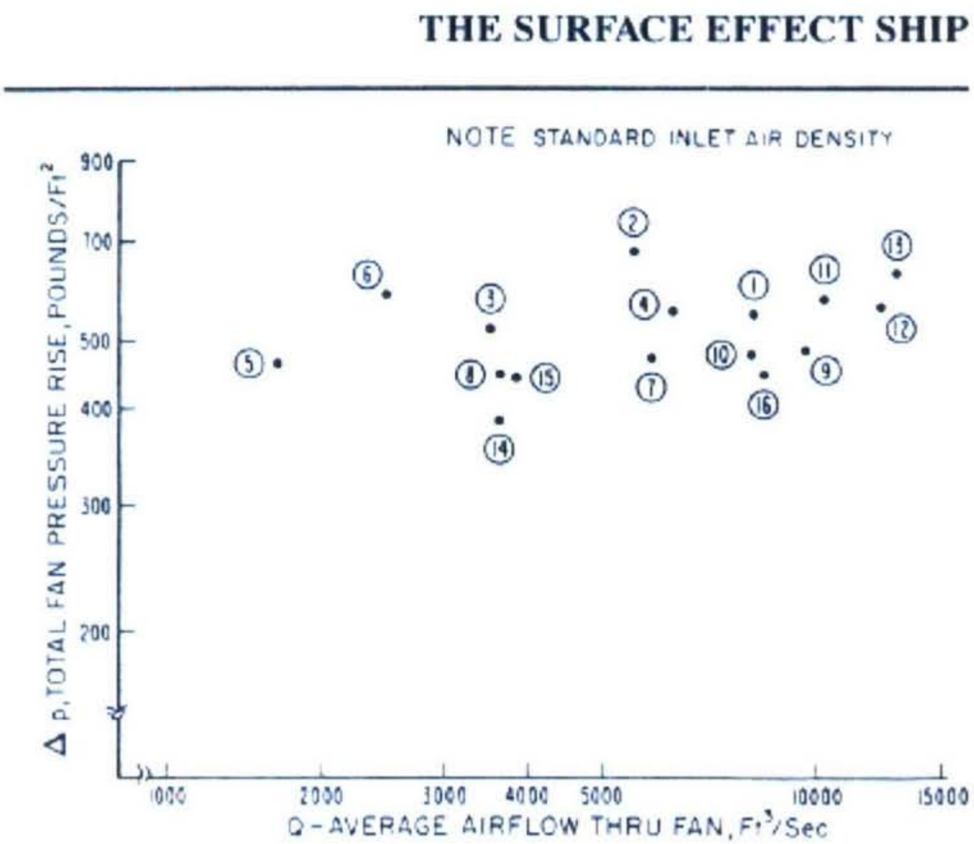


**Figure 51. Pressure-Flow Duty Points of Typical Operational Large NEU Fans Installed in the Past 15 Years.**

**Figure 3-25 – Flow & Pressure Ratings for RD Fans Built More than 40 Years ago**

The head and flow characteristics produced by fans designed to satisfy the HSSL requirements are shown in Figure 3-26 through Figure 3-29. Figure 3-26 and Figure 3-27 show results for SWSI fans, and Figure 3-28 and Figure 3-29 show results for DWDI (Double-Width/Double-Inlet) fans, where the first figure is for the shallow draft mode and the second figure is for the SWATH mode in each case.

Either SWSI or DWDI fans could be used; however, the SWSI fans seemed to be more suitable for the HSSL arrangement and these are featured in the current design, but could be changed with minimum impact after more in-depth analysis. Details from the analysis of these fans are shown in Section 3.8.4 in which fan impeller diameter was varied from 8 to 9.1 ft. Tip speeds on these fans are high, but well below the levels produced in the past. However, when used in the dynamic environment of a vessel at sea, care will need

to be taken in the design of bearing supports to resist the added loads from gyroscopic motion.

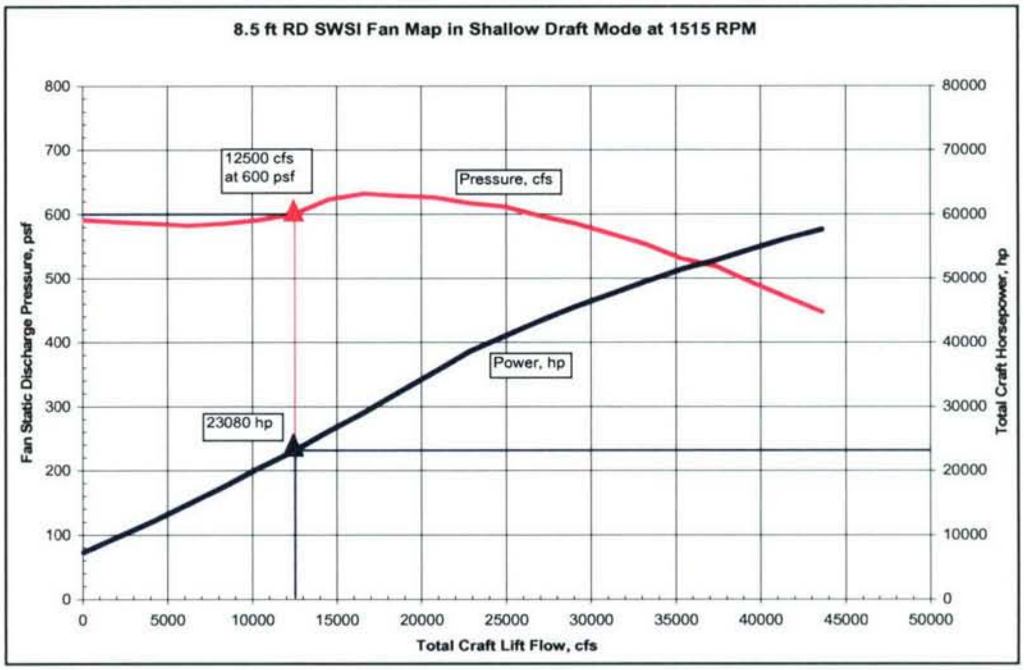


**Figure 3-26 – 8.5 ft RD SWSI Fan Pressure & Power vs. Flow Characteristics for Shallow Draft Operation**

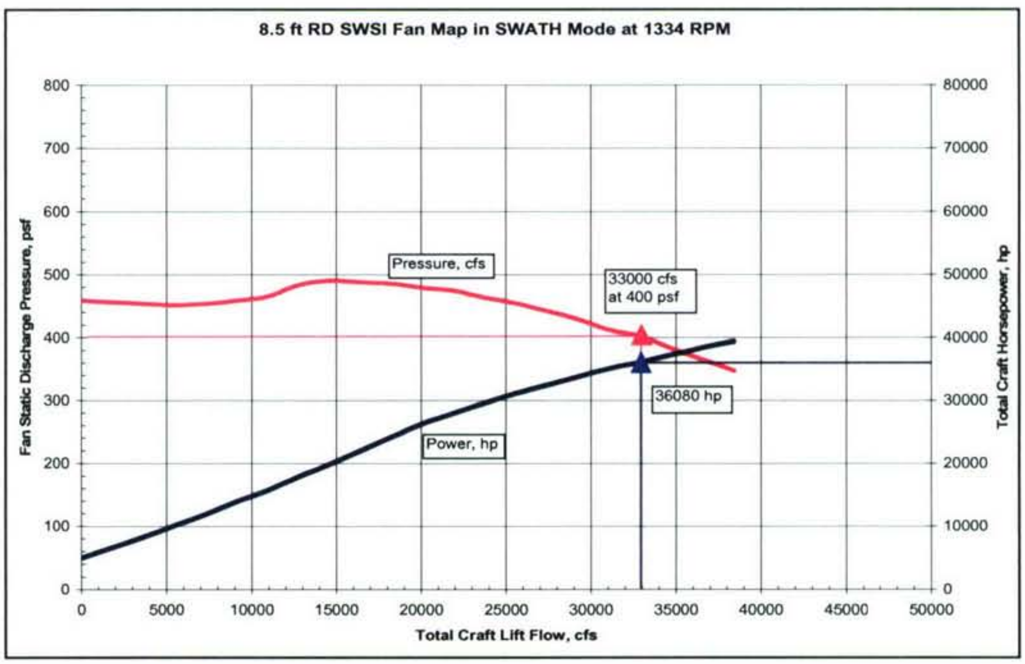


**Figure 3-27 – 8.5 ft RD SWSI Fan Pressure & Power vs. Flow Characteristics for SWATH Mode Operation**

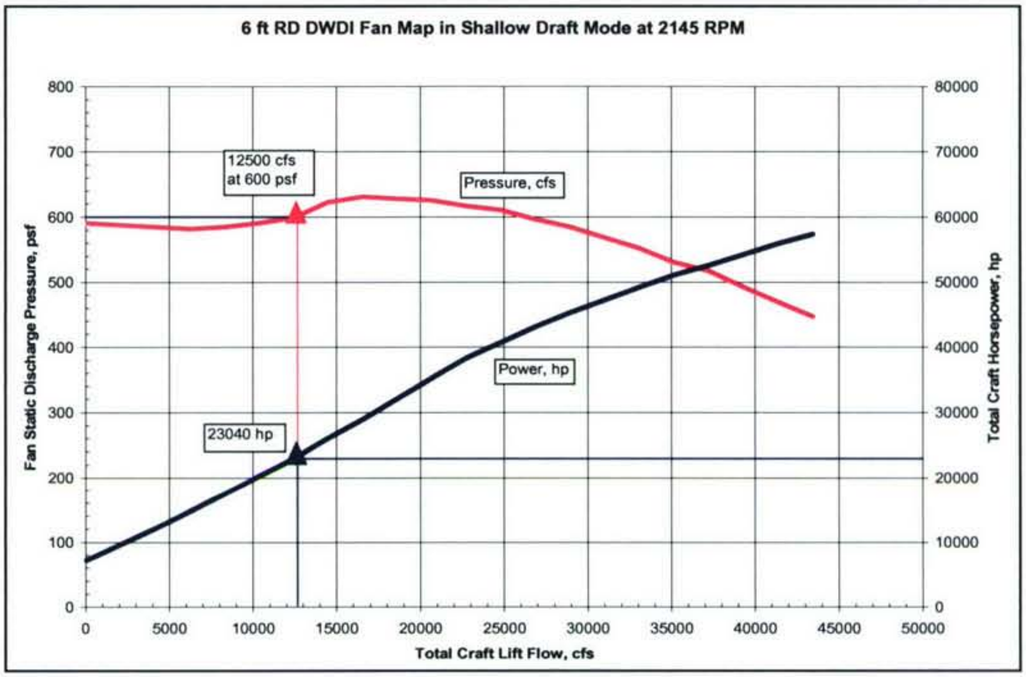


**Figure 3-28 – 6 ft RD DWDI Fan Pressure & Power vs. Flow Characteristics for Shallow Draft Operation**

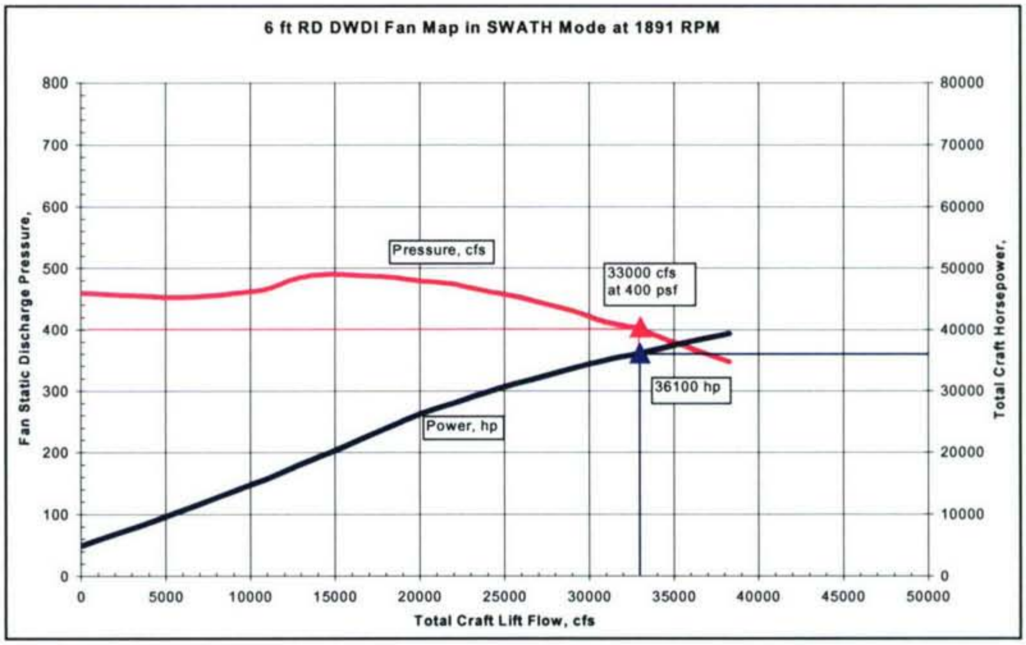


**Figure 3-29 – 6 ft RD DWDI Fan Pressure & Power vs. Flow Characteristics for SWATH Mode Operation**

### 3.8.3 SES Cushion Seal System

The HSSL concept reported herein is designed to operate as an SES in two different modes:

1. On full cushion to reduce the ship's full-load draft to less than 6.5 m. This was necessary to allow the ship to gain access to shallow draft ports.
2. On partial cushion in the SWATH mode to provide ship pitch and heave motion control from active control of the large aerostatic forces and moments available from the SES cushion. This was considered necessary to reduce to an acceptable level the relative motion and the risk of loading and unloading cargo at the sea base in heavy seas.

To achieve these modes of operation, the vessel is equipped with end seals fore and aft to impede the flow of air from the cushion. For the SWATH mode, another seal close to amidships is used to split the SES cushion into fore and aft compartments. All three seals are attached to the hard structure of the ship. They are all flexible as they are made of a combination of natural rubber and neoprene-coated nylon fabric. However, all seals need, ideally, to have a means to be retracted for vessel operation in the catamaran mode. During the model tests, it was determined that for the transition between the full cushion shallow draft mode and the SWATH mode, the seals did not need to have their heights adjusted.

The three seals are referred to as the bow seal, the stern seal, and the cushion divider. The stern seal and the cushion divider require a separate air supply in order to maintain their proper operating shape; the bow seal does not.

#### *3.8.3.1 Bow Seal*

This seal is a full-depth finger seal somewhat similar to what is featured on most SES in recent times, but first created in the mid 1960's. See the general arrangement drawing of Figure A-3 in Appendix A2. It was the seal that was tested at DTMB in December 2006 on a model of the concept reported herein. The bow seal on this model is shown in Figure 3-30. This seal maintains its shape by cushion pressure acting on the inside of the seal. A possible alternative to this seal was a bag and finger seal, similar to the skirts on the USN LCAC, but it was considered more difficult to retract than the full-depth finger seal. Although a bag and finger seal would require a separate air supply similar to the stern seal and cushion divider, it would allow individual fingers to be less tall and permit the use of a much larger number of fingers compared to the three tested on the model last December. Since tall narrow fingers can hang up in operation, and space they would otherwise occupy would be taken up with adjacent fingers, such a seal can become grossly distorted and not seal well. By having more individual fingers, each finger will have a smaller radius and less membrane tension for a given pressure and thus be more responsive to seal the cushion in a seaway. This option should be revisited during the next phase of design.

The retraction of the bow seal for catamaran operation is considered necessary to minimize environmental stress on the seal. The details of the approach to retraction have not been examined in this study, but earlier studies have shown that by attaching straps to the hemline of each finger, the fingers can have their length shortened by pulling the fingers up from their bottom as one might pull up by hand the pant legs of a pair of trousers.

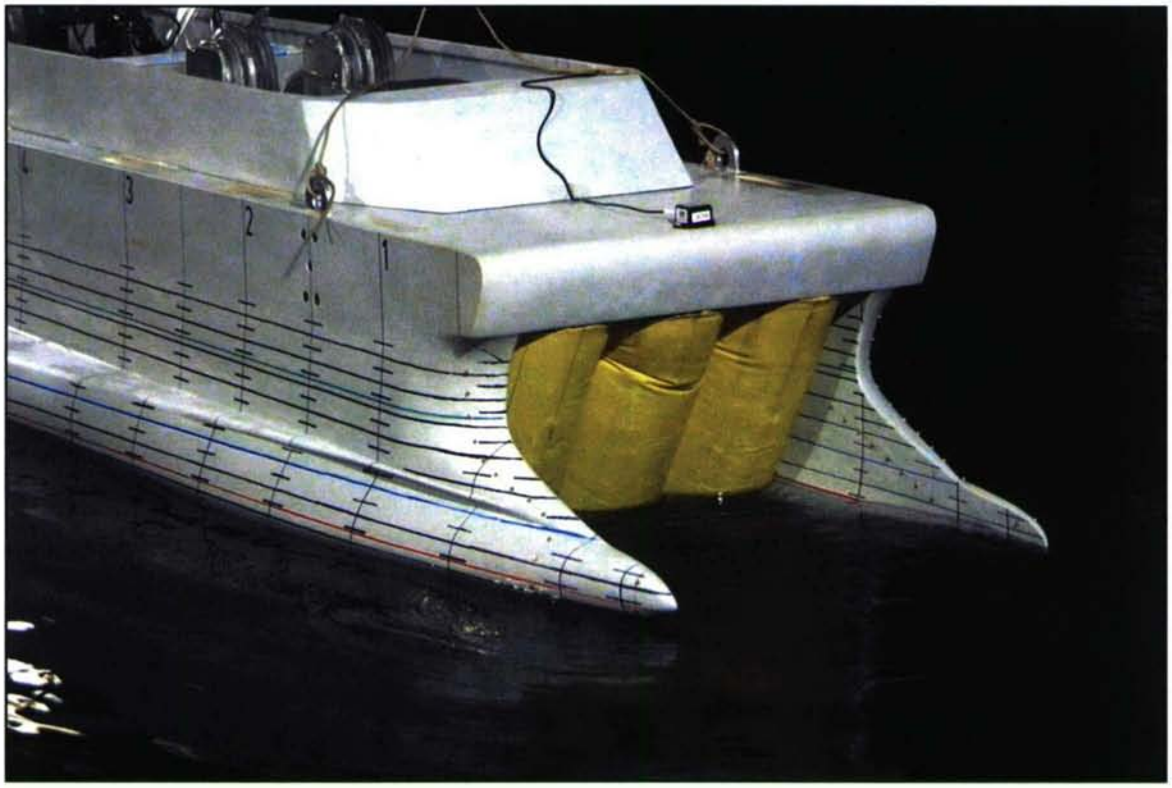

**Figure 3-30 – Full Depth Bow Finger Seal for HSSL Model in Shallow-Draft SES Mode**

### 3.8.3.2 *Stern Seal*

The stern seal is a triple-lobe seal inflated by boosting cushion air with a separate set of fans and ducting within the ship's hard structure from the cushion to the seal, as shown in the general arrangement drawings of Figure A-10 and Figure A-14 in Appendix A2. For operation in low sea states and calm water, the pressure in the seal is required to be about 5% above cushion pressure. For operation in heavier seas, the pressure in the stern seal would be reduced to approach a value of 1% greater than cushion pressure. This lowering of the seal pressure in heavier seas allows the bottom of the seal to more readily track the surface of the waves with minimum drag and stress and, in turn, creates a better seal for the cushion, particularly with forward motion on the ship in head seas.

The retraction of this seal for the catamaran mode is achieved with straps that are permanently in place to envelope the seal, with one end of each strap fixed to an attachment on the ship and the other end attached to a winch on the ship. The seal used on the model is shown in Figure 3-31. This shows that the model was equipped with two

straps (not shown in operation) whereas the full-scale vessel would have many more. As mentioned before, it was demonstrated that height adjustment of the bow and stern seals was not necessary in converting the ship from shallow draft to SWATH mode of operation.

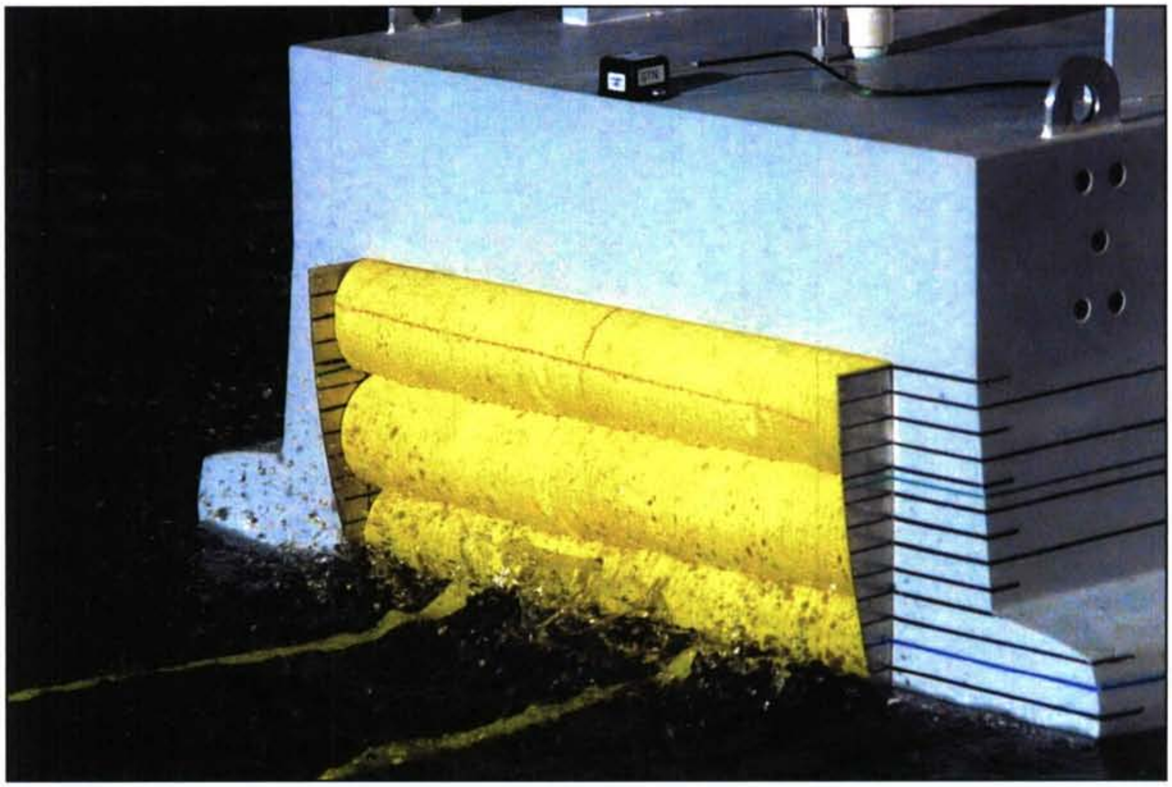

**Figure 3-31 – Triple-Lobe Stern Seal for HSSL Model in Shallow-Draft SES Mode**

#### *3.8.3.3 Cushion Divider*

The cushion divider splits the cushion into fore and aft compartments and, when inflated and in use, has its hemline close to the sea surface inside the cushion and acts to impede the flow of cushion air beneath its hemline. Thus, it is capable of allowing the two compartments to operate at different pressures as required by the motion control system in controlling motion in pitch. This approach to SES motion control was first successfully tried on a model of the German Navy SES 700 by DTMB in the early 90's. For both the SES 700 and the HSSL model tested in December 2006, the cushion divider was designed and constructed by CDIM-SDD (formerly BLA) and was similar to the transverse seal designed by BLA for the Deep Skirt on the LCAC. The cushion divider on the HSSL model is shown in Figure 3-32. The full-scale seal is shown in the general arrangement drawing of Figure A-10 in Appendix A2. It is basically a bag and finger seal, with the bag inflated to a pressure 30% greater than cushion pressure, and fingers actually replaced by cones (instead of open fingers) that have drain holes along their bottom.

This seal is also of a fixed height when in use to divide the cushion in the SWATH mode. In the shallow-draft SES mode, the height of its bottom above the water surface is therefore large and thus it does not interfere with operation of the ship. In the catamaran mode, the seal is retracted with straps in the same way as the stern seal is retracted.

**Figure 3-32 – Transverse Seal Cushion Divider for HSSL Model**

### 3.8.4 Supporting Calculations

```
FAN DIMENSIONLESS CHARACTERISTICS - PROGRAM NAME: FANDC
                    ---------------------------------   -------------------
                                  FAN TYPE - RD
                          ********************************
                    THIS RUN IS FOR HSSL IN SHALLOW DRAFT MODE

INLET TOTAL PRESSURE =  14.696 PSIA                      CUSHION DEPTH          = 51.08 FT
AMBIENT TEMPERATURE  =  70.0 DEG.F                       CUSHION BEAM           =  70.7 FT
RELATIVE HUMIDITY    =  50.0 %                           FAN WIDTH FACTOR       = .0800
DENSITY              =  .0023166 SLUGS/CU FT             FAN EXIT AREA RATIO    = .4500
STATIC DISCHARGE PRESS. COEFFS. ARE INPUT       FAN-CUSH. PRESS. DROP COEFF.    = 8.4E-06
                                FAN WIDTH CALCULATIONS
```

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FANDISCHARGE PRESSURE, TOTAL (PSF) | 610.70 | 610.21 | 609.75 | 609.31 | 608.90 | 608.51 | 608.15 |
| FAN DISCHARGE PRESSURE, STATIC (PSF) | 600.00 | 600.00 | 600.00 | 600.00 | 600.00 | 600.00 | 600.00 |
| FAN DISCHARGE TEMPERATURE (DEG F) | 142.17 | 143.01 | 143.82 | 144.61 | 145.38 | 146.11 | 146.82 |
| TEMPERATURE RISE IN FAN (DEG F) | 72.166 | 73.008 | 73.824 | 74.615 | 75.378 | 76.113 | 76.821 |
| FLOW RATE-SINGLE FAN*AMBIENT CONDITIONS (CFS) | 3125.00 | 3125.00 | 3125.00 | 3125.00 | 3125.00 | 3125.00 | 3125.00 |
| FLOW RATE-DOUBLE FAN*AMBIENT CONDITIONS (CFS) | 6250.00 | 6250.00 | 6250.00 | 6250.00 | 6250.00 | 6250.00 | 6250.00 |
| IMPELLER DIAMETER (FT) | 8.5000 | 8.6000 | 8.7000 | 8.8000 | 8.9000 | 9.0000 | 9.1000 |
| IMPELLER DIAMETER (IN) | 102.0000 | 103.2000 | 104.4000 | 105.6000 | 106.8000 | 108.0000 | 109.2000 |
| VOLUTE DISCHARGE AREA (FT2) | 32.5125 | 33.2820 | 34.0605 | 34.8480 | 35.6445 | 36.4500 | 37.2645 |
| VOLUTE EXIT VELOCITY (FPS) | 96.117 | 93.895 | 91.749 | 89.675 | 87.671 | 85.734 | 83.860 |
| EXIT DYNAMIC PRESSURE (LBF/FT2) | 10.701 | 10.212 | 9.750 | 9.315 | 8.903 | 8.514 | 8.146 |
| FAN SPEED (RPM) | 1515.1 | 1501.4 | 1487.3 | 1472.5 | 1457.4 | 1441.9 | 1426.3 |
| IMPELLER TIP SPEED (FPS) | 674.29 | 676.09 | 677.50 | 678.50 | 679.15 | 679.49 | 679.61 |
| FAN HORSEPOWER-SINGLE WIDTH FAN | 5768.77 | 5832.56 | 5894.46 | 5954.53 | 6012.57 | 6068.51 | 6122.38 |
| FAN HORSEPOWER-DOUBLE WIDTH FAN | 11537.53 | 11665.12 | 11788.93 | 11909.06 | 12025.13 | 12137.01 | 12244.75 |
| FAN TOTAL EFFICIENCY | .6015 | .5944 | .5878 | .5814 | .5754 | .5697 | .5644 |
| FAN STATIC EFFICIENCY | .5910 | .5845 | .5784 | .5725 | .5670 | .5618 | .5568 |
| IDEAL NOZZLE THRUST (LBF) | 5256.60 | 5254.49 | 5252.51 | 5250.63 | 5248.85 | 5247.18 | 5245.59 |
| IDEAL THRUST/HP RATIO (LBF/HP) | .9112 | .9009 | .8911 | .8818 | .8730 | .8647 | .8568 |
| IDEAL NOZZLE AREA (FT2) | 4.3037 | 4.3055 | 4.3071 | 4.3086 | 4.3101 | 4.3115 | 4.3128 |
| IDEAL NOZZLE DIAMETER (FT) | 2.3409 | 2.3413 | 2.3418 | 2.3422 | 2.3426 | 2.3430 | 2.3433 |
| IDEAL NOZZLE VELOCITY (FPS) | 726.11 | 725.82 | 725.55 | 725.29 | 725.04 | 724.81 | 724.59 |
| FLOW COEFFICIENT | .2552 | .2487 | .2425 | .2366 | .2311 | .2259 | .2209 |
| STATIC PRESSURE COEFFICIENT | .5697 | .5666 | .5643 | .5626 | .5615 | .5610 | .5608 |
| TOTAL PRESSURE COEFFICIENT | .5798 | .5763 | .5734 | .5713 | .5699 | .5689 | .5684 |
| STATIC DIAMETER COEFFICIENT | .7525 | .7614 | .7703 | .7791 | .7880 | .7968 | .8057 |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| TOTAL DIAMETER COEFFICIENT | .7559 | .7646 | .7734 | .7821 | .7909 | .7996 | .8084 |
| DXDY | 1.866 | 1.862 | 1.858 | 1.855 | 1.852 | 1.849 | 1.847 |
| FAN SLOPE-SINGLE FAN | 21.686 | 22.096 | 22.524 | 22.971 | 23.436 | 23.918 | 24.414 |
| FAN SLOPE -DOUBLE FAN | 43.373 | 44.192 | 45.047 | 45.942 | 46.872 | 47.836 | 48.829 |
| CUSHION SLOPE-SINGLE FAN | -160.956 | -141.493 | -126.147 | -113.746 | -103.565 | -95.099 | -87.986 |
| CUSHION SLOPE-DOUBLE FAN | -321.912 | -282.985 | -252.295 | -227.492 | -207.129 | -190.197 | -175.973 |
| STABILITY INDEX-SINGLE FAN | .1732 | .1526 | .1364 | .1232 | .1125 | .1035 | .0960 |
| STABILITY INDEX-DOUBLE FAN | .3465 | .3052 | .2727 | .2465 | .2249 | .2070 | .1919 |
| FAN CUSHION PRESSURE DROP (PSF) | 81.7578 | 81.7578 | 81.7578 | 81.7578 | 81.7578 | 81.7578 | 81.7578 |
| CUSHION PRESSURE (PSF) | 518.242 | 518.242 | 518.242 | 518.242 | 518.242 | 518.242 | 518.242 |
| FAN/CUSHION PRESSURE RATIO | 1.1578 | 1.1578 | 1.1578 | 1.1578 | 1.1578 | 1.1578 | 1.1578 |

FAN DIMENSIONLESS CHARACTERISTICS - PROGRAM NAME: FANDC

FAN TYPE - RD

********************************

**THIS RUN IS FOR HSSL IN SWATH MODE**

INLET TOTAL PRESSURE = 14.696 PSIA
AMBIENT TEMPERATURE = 70.0 DEG.F
RELATIVE HUMIDITY = 50.0 %
DENSITY = .0023166 SLUGS/CU FT
STATIC DISCHARGE PRESS. COEFFS. ARE INPUT

CUSHION DEPTH = 51.08 FT
CUSHION BEAM = 70.7 FT
FAN WIDTH FACTOR = .0800
FAN EXIT AREA RATIO = .4500
FAN-CUSH. PRESS. DROP COEFF. = 8.4E-06

FAN WIDTH CALCULATIONS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FANDISCHARGE PRESSURE, TOTAL (PSF) | 495.05 | 490.44 | 486.11 | 482.03 | 478.20 | 474.58 | 471.17 |
| FAN DISCHARGE PRESSURE, STATIC (PSF) | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 |
| FAN DISCHARGE TEMPERATURE (DEG F) | 108.30 | 108.22 | 108.10 | 107.96 | 107.84 | 107.84 | 108.04 |
| TEMPERATURE RISE IN FAN (DEG F) | 38.296 | 38.222 | 38.101 | 37.958 | 37.845 | 37.840 | 38.038 |
| FLOW RATE-SINGLE FAN*AMBIENT CONDITIONS (CFS) | 8250.00 | 8250.00 | 8250.00 | 8250.00 | 8250.00 | 8250.00 | 8250.00 |
| FLOW RATE-DOUBLE FAN*AMBIENT CONDITIONS (CFS) | 16500.00 | 16500.00 | 16500.00 | 16500.00 | 16500.00 | 16500.00 | 16500.00 |
| IMPELLER DIAMETER (FT) | 8.0000 | 8.1000 | 8.2000 | 8.3000 | 8.4000 | 8.5000 | 8.6000 |
| IMPELLER DIAMETER (IN) | 96.0000 | 97.2000 | 98.4000 | 99.6000 | 100.8000 | 102.0000 | 103.2000 |
| VOLUTE DISCHARGE AREA (FT2) | 28.8000 | 29.5245 | 30.2580 | 31.0005 | 31.7520 | 32.5125 | 33.2820 |
| VOLUTE EXIT VELOCITY (FPS) | 286.458 | 279.429 | 272.655 | 266.125 | 259.826 | 253.749 | 247.882 |
| EXIT DYNAMIC PRESSURE (LBF/FT2) | 95.048 | 90.441 | 86.109 | 82.034 | 78.196 | 74.581 | 71.172 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FAN SPEED (RPM) | 1472.6 | 1442.9 | 1414.0 | 1385.6 | 1358.6 | 1333.6 | 1311.7 |
| IMPELLER TIP SPEED (FPS) | 616.85 | 611.95 | 607.11 | 602.16 | 597.55 | 593.53 | 590.64 |
| FAN HORSEPOWER-SINGLE WIDTH FAN | 9422.20 | 9337.68 | 9247.50 | 9156.50 | 9075.25 | 9020.06 | 9010.28 |
| FAN HORSEPOWER-DOUBLE WIDTH FAN | 18844.40 | 18675.35 | 18495.01 | 18312.99 | 18150.51 | 18040.11 | 18020.56 |
| FAN TOTAL EFFICIENCY | .7881 | .7878 | .7885 | .7897 | .7904 | .7892 | .7844 |
| FAN STATIC EFFICIENCY | .6368 | .6426 | .6488 | .6553 | .6611 | .6652 | .6659 |
| | | | | | | | |
| IDEAL NOZZLE THRUST (LBF) | 12494.48 | 12436.20 | 12381.16 | 12329.15 | 12279.98 | 12233.47 | 12189.46 |
| IDEAL THRUST/HP RATIO (LBF/HP) | 1.3261 | 1.3318 | 1.3389 | 1.3465 | 1.3531 | 1.3563 | 1.3528 |
| IDEAL NOZZLE AREA (FT2) | 12.6195 | 12.6786 | 12.7350 | 12.7887 | 12.8399 | 12.8887 | 12.9352 |
| IDEAL NOZZLE DIAMETER (FT) | 4.0084 | 4.0178 | 4.0267 | 4.0352 | 4.0433 | 4.0510 | 4.0583 |
| IDEAL NOZZLE VELOCITY (FPS) | 653.75 | 650.70 | 647.82 | 645.10 | 642.53 | 640.10 | 637.79 |
| | | | | | | | |
| FLOW COEFFICIENT | .8315 | .8176 | .8041 | .7913 | .7785 | .7655 | .7514 |
| STATIC PRESSURE COEFFICIENT | .4538 | .4611 | .4685 | .4762 | .4836 | .4901 | .4949 |
| TOTAL PRESSURE COEFFICIENT | .5616 | .5653 | .5693 | .5739 | .5781 | .5815 | .5830 |
| STATIC DIAMETER COEFFICIENT | .3939 | .3988 | .4037 | .4087 | .4136 | .4185 | .4234 |
| TOTAL DIAMETER COEFFICIENT | .4155 | .4197 | .4239 | .4282 | .4325 | .4368 | .4411 |
| | | | | | | | |
| DXDY | 2.664 | 2.627 | 2.593 | 2.562 | 2.531 | 2.502 | 2.471 |
| FAN SLOPE-SINGLE FAN | 29.984 | 30.558 | 31.156 | 31.794 | 32.430 | 33.039 | 33.566 |
| FAN SLOPE -DOUBLE FAN | 59.968 | 61.115 | 62.313 | 63.589 | 64.860 | 66.077 | 67.133 |
| CUSHION SLOPE-SINGLE FAN | -9.543 | -9.487 | -9.430 | -9.373 | -9.319 | -9.270 | -9.230 |
| CUSHION SLOPE-DOUBLE FAN | -19.086 | -18.973 | -18.860 | -18.747 | -18.639 | -18.541 | -18.459 |
| STABILITY INDEX-SINGLE FAN | .0239 | .0238 | .0237 | .0237 | .0236 | .0235 | .0235 |
| STABILITY INDEX-DOUBLE FAN | .0477 | .0476 | .0474 | .0473 | .0472 | .0471 | .0470 |
| | | | | | | | |
| FAN CUSHION PRESSURE DROP (PSF) | 569.8192 | 569.8192 | 569.8192 | 569.8192 | 569.8192 | 569.8192 | 569.8192 |
| CUSHION PRESSURE (PSF) | -169.819 | -169.819 | -169.819 | -169.819 | -169.819 | -169.819 | -169.819 |
| FAN/CUSHION PRESSURE RATIO | -2.3554 | -2.3554 | -2.3554 | -2.3554 | -2.3554 | -2.3554 | -2.3554 |

**Table 3-10 – Cargo Hold Ventilation System Sizing**

| Deck | Area ($in^2$) | Area ($ft^2$) | Deck Height (ft) | Volume ($ft^3$) | Reqd Air Volume Exchange /hr | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|---|---|---|---|
| 01 Level | 5,028,727 | 34,922 | 11.0 | 384,139 | 7,682,777 | 1.0 | 1.2 | 3.6 | 16.5 |
| Main | 5,592,280 | 38,835 | 11.5 | 446,606 | 8,932,114 | 1.2 | 1.4 | 4.1 | 19.2 |
| B Deck | 218,398 | 1,517 | 24.0 | 36,400 | 727,993 | 0.1 | 0.1 | 0.3 | 1.6 |
| | 1,253,359 | 8,704 | 24.0 | 208,893 | 4,177,864 | 0.5 | 0.6 | 1.9 | 9.0 |
| | 1,109,583 | 7,705 | 24.0 | 184,931 | 3,698,610 | 0.5 | 0.6 | 1.7 | 7.9 |
| | 861,726 | 5,984 | 24.0 | 143,621 | 2,872,421 | 0.4 | 0.4 | 1.3 | 6.2 |
| (subtotal) | 3,443,067 | 23,910 | | 573,844 | | | | | |
| TOTAL: | 14,064,073 | 97,667 | | **1,404,589** | 28,091,779 | 3.7 | 4.3 | 13.0 | 60.4 |

| | |
|---|---|
| Total Volume Exchange Per Hour ($ft^3$) | **28,091,779** |

20 (20 total air exchanges per hour, as stipulated in ABS HSNC Rules)
Part 4 - Craft Systems and Machinery
Chapter 7 - Fire Safety Systems
Section 1 - Fire Extinguishing Systems and Equipment
19.11.1 - Ventilation System (Capacity)

| | | $m^3/hr$ | | $ft^3/hr$ | ft |
|---|---|---|---|---|---|
| 1 | Fan Capacity | 216,660 | | 7,651,348 | 8.72 (L) x 5.84 Φ |
| 2 | Fan Capacity | 183,493 | → | 6,480,055 | 8.72 (L) x 5.84 Φ |
| 3 | Fan Capacity | 61,164 | | 2,160,007 | 6.60 (L) x 4.3 Φ |
| 4 | Fan Capacity | 13,176 | | 465,310 | 3.60 (L) x 3.7 Φ |

T-AKE Machinery Space Fans

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### 3.8.5 General and Machinery Arrangements

The initial plan was to design the ship with a direct mechanical drive, with Gas Turbines appropriately geared to the axial-flow Waterjets. However, it quickly became apparent that the vessel did not have sufficient hull volume to make such an arrangement workable, especially considering both the fuel and ballast volume required to meet the desired mission capabilities. This realization led to the design of an Electric Ship architecture that made it possible to relocate the power sources outside of the actual demihulls to another area of the ship.

The following sections thus provide a description of the general arrangements, based on the application of an Integrated Power System (IPS) representative of an Electric Ship Propulsion and Power Generation and Distribution system architecture, details of which are discussed in Section 3.7 on the Electric Plant. The basic elements of the arrangements are defined in Sections 3.8.5.1 and 3.8.5.2 which follow, starting with the outboard and inboard profiles and then stepping through the individual deck plans working from the upper most deck levels to the lower levels and from bow to stern.

#### *3.8.5.1 GA Profile Views – Outboard & Inboard*

The outboard profile, as shown in Figure A-2 in Appendix A2, illustrates the vessel with the location of some of the external outfitting such as railings and ladders, the air supply and exhaust for the various ventilation fans located in the cargo holds, and the air intakes for the Gas Turbine Generators as well as their exhausts. Also included are the Bow and Stern views showing the hull geometry and some of the more prominent outfitting features like the Advanced Enclosed Mast/Sensor (AEM/S) system and the stern slewing ramp. A table of Principal Characteristics is shown in the top left corner of the sheet.

Three inboard profiles are shown Figure A-3 and Figure A-4 in Appendix A2, one on centerline, one 27 feet off of centerline to port, and one 40.3 feet off of centerline. The centerline cut is intended to show the unobstructed nature of the vehicle stowage spaces and location of B Deck to Main Deck retractable ramps. The off centerline cut depicts the fact that there are six large Auxiliary Machinery Rooms (AMR's), three port and three starboard, with their longitudinal extents shown and with transverse extents starting with an inboard bulkhead located 9 feet off of centerline and extending to the shell of the ship. This clearly impacted the amount of arrangeable payload space. Also shown on both views is the location and configuration of the bow seal, cushion divider, and the stern seal. The 40.3-foot inboard profile highlights the arrangement of Fuel and Ballast tankage as well as the Propulsion Motor and Waterjet Propulsor machinery spaces.

All profile views clearly demark the frame locations and frame spacing as well as a number of the important measurements, including LPB, LOA, critical waterline heights, and deck heights.

### 3.8.5.2 GA Deck Plans

03 Level (see Figure A-5 in Appendix A2)

This level carries an Advanced Enclosed Mast/Sensor System, a design that seeks to limit radar signature by shape (hexagonal shape and 10-degree slope) and enclosing key radar components. The mast is a large composite structure, the upper half of which is radar frequency transparent, permitting the transmission of selective radar frequencies and integrated communication energy through the mast's surface. The lower half of the mast is radar reflective and the entire mast is part of an integrated EMI/EMP management system. A similar system is currently deployed on the LPD-17 class Amphibious Assault ships. This level also includes crew accommodations, crew laundry, a gymnasium, and the medical treatment room.

02 Level (see Figure A-5 in Appendix A2)

The ship's bridge is located on this level as well as the IC/Radar and Gyro room. In addition, there is a large conference room, Officer and CPO staterooms, and the Galley and Crew Mess.

Separated from the crew accommodations is the Gas Turbine Generator (GTG) Main Machinery Room (MMR), which highlights the arrangement of six (6) 50 MW MT50 based GTG's. Two (2) pairs are arranged in a TwinPack configuration, implying that two (2) 50 MW Gas Turbines provide power to a single 100 MW Generator. The remaining two (2) Gas Turbines feed power to one (1) 50 MW Generator each. Profile and plan views of this machinery arrangement are shown in Figure A-9 and Figure A-12 in Appendix A3. It is important to note that the dotted lines around each unit represent the overall footprint including the Gas Turbine/s, the Generator, and associated Ancillary Equipment. As shown by the heavy weighted line, much of the entire port and starboard side of the MMR enclosure represents the air filtration system for the Gas Turbine intakes. These are provided with dual stage filtration elements and are fitted with louvers on the outboard-most surface to prevent ingestion of water and other debris from the outside environment. Entry to the MMR is provided both via a vestibule connected to the accommodation spaces, with suitable separation to insulate those living spaces from any noise and vibration from the Generator Sets, and also from the weather deck.

Finally, a Hangar and Flight Deck are provided to enable air operations for a V-22 Osprey tilt rotor aircraft (depicted on the Topside view on the flight deck and on the 02 Level in the stowed position inside the Hangar), envisioned to be one of the likely seabasing air support (VERTREP) assets.

01 Level (see Figure A-6 in Appendix A2)

This level is an open cargo hold intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment. Frame 40 on the port side this deck features a Retractable Watertight Ramp to the Main Deck below. Forward (frame 14) and aft

(frame 88) Air Ventilation Supply and Exhaust Fans, depicted both port and starboard, serve to exchange the entire air volume in the hold during onload and offload sequences.

Main Deck (see Figure A-6 in Appendix A2)

This level is also cargo hold intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment.

This deck provides direct access to the retractable Bow Ramp envisioned primarily for conducting ship-to-ship (i.e. LDS-HSC-to-LMSR) cargo transfer at sea.

In addition to the port Retractable Watertight Ramp at frame 40 that services the 01 level, this deck has two centerline Retractable Watertight Ramps, one at frame 8 and the other at frame 71, which provide access to the B Deck below.

Air Ventilation Supply and Exhaust Fans, located on the port side at frames 19, 30 and 57 and on the starboard side at frames 27, 39 and 69, serve to exchange the entire air volume in the hold during onload and offload sequences.

The two lifeboat stations, one starboard and one port, are located between frames 46 and 51.

B Deck (see Figure A-7 in Appendix A2)

This level houses six Auxiliary Machinery Rooms (AMR's), three on the port side and three to starboard. AMR1 (P&S), located between frames 10 and 20, contains bow ramp machinery, anchor handling equipment, and SES machinery for operation of the forward bow seal. AMR2 (P&S), located between frames 41 and 55, details of which are shown in Figure A-9 and Figure A-13 in Appendix A3, houses all the machinery for the SES Cushion Lift-Air Supply system for operation of the forward and aft cushions as well as the Cushion Divider. AMR3 (P&S), located between frames 71 and the Aft Perpendicular, contains the SES stern seal machinery as well as the six motor drives, details for which are shown in Figure A-10 and Figure A-14 in Appendix A3. In addition, this level is intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment. Three hoistable decks are provided to make use of this deck's 22-foot clear height.

This deck also features two centerline Retractable Watertight Ramps, one at frame 8 and the other at frame 71, which provide access to the Main Deck above.

This deck provides direct access to the Stern Slewing Ramp for conducting cargo onload and offload operations in port.

Air Ventilation Supply and Exhaust Fans located on the port side at frames 19, 30 and 57 and on the starboard side at frames 27, 39 and 69 serve to exchange the entire air volume in the hold during onload and offload sequences.

Watertight doors are provided at each of the main watertight bulkhead locations to comply with the damage stability requirements and insure the ship's survivability.

C Deck (see Figure A-8 in Appendix A2)

This deck forms the transition between the struts and the demihulls, and the volume between it and the Wet Deck is used to provide for a portion of the ship's overall Fuel and Ballast capacity. The space between frames 71 and 83 constitutes the second level of the Propulsion Machinery Room.

D Deck (see Figure A-8 in Appendix A2)

This deck represents the lowest continuous deck of the ship. The demihull volume between it and the C Deck is used to provide for the majority of the ship's overall Fuel and Ballast capacity. The space between frames 71 and 83 constitutes the main level of the Propulsion Machinery Room. The Waterjet machinery space is located aft of frame 83. The arrangements of these machinery spaces are shown in Figure A-11 and Figure A-15 in Appendix A3 and discussed in more detail in Section 3.6. Sectional views of the machinery arrangements are provided in Figure A-16 in Appendix A3.

#### *3.8.5.3 Payload Arrangements*

01 Level (see Figure A-18 in Appendix A4)

This level is intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment. In order to keep the composite VCG of the vessel low, this deck was arranged, as much as possible, with lighter weight vehicles. The details of what specific cargo is stored on this level are shown in Table 3-11. This deck also features a Retractable Watertight Ramp at frame 40 on the port side that provides for the movement of vehicles to and from the Main Deck below. As can be seen in Figure A-18, the payload was arranged in such a way as not to conflict with ship's structural support columns and to keep the defined flow path as open as possible to allow for the efficient onload and offload of vehicles.

Main Deck (see Figure A-18 in Appendix A4)

This level is intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment. This deck is intended for the stowage of some of the heavier and most voluminous of the vehicle cargo. Details of what specific cargo is stored on this level are shown Table 3-11. Three ramps, two located on centerline forward and aft in the hold, and one on the port side in the midships area are provided to allow for ease in moving cargo between the different decks. This deck also provides direct access to the retractable Bow Ramp envisioned primarily for conducting ship-to-ship (i.e. LDS-HSC-to-LMSR) cargo transfer at sea.

B Deck (see Figure A-19 in Appendix A4)

This level is intended for the arrangement of the LDS-HSC's payload of vehicles and related support equipment. The deck is intended to hold some of the heaviest and most voluminous of the vehicle cargo. Details of what cargo is stored on this level are shown in Table 3-11. This deck has direct access to the 3-point Stern Slewing Ramp and is therefore envisioned as the entry point for loading and unloading cargo in port. Two ramps located on the ship's centerline provide access to the Main Deck above. The first is located aft and is intended as the primary means of getting vehicles to the Main Deck during an in-port loading evolution. The second of these is located forward and provides direct access to the main deck bow ramp for offloading of cargo during an at-sea cargo transfer.

B Deck is also outfitted with three hoistable decks, one between frames 18 and 29, the second between frames 30 and 41, and the third between frames 55 and 71. These are intended to be loaded with lighter weight and low height vehicles such as HMMV's and their cargo trailers. This arrangement makes efficient use of the large clear height available on this deck, driven primarily by the structural requirements of the cross deck and also by the height requirements associated with the SES Cushion Lift-Air Supply system machinery.

## 3.8.6 General Arrangement Supporting Information

### *3.8.6.1 Vehicle Cargo Locations*

Table 3-11 describes the specific vehicle cargo types and their quantities and location on the ship.

**Table 3-11 – Listing of Vehicle Types, Locations, and Quantities**

| TYPE | DESCRIPTION | REQUIRED QTY | LOCATIONS/QTY | | | | |
|---|---|---|---|---|---|---|---|
| | | | "B" Deck | Main Deck | Hoistable A | Hoistable B | 01 Level |
| M1135 | NBC RECONNAISSANCE VEHICLE | 3 | | | | | 3 |
| M1127 | RECONNAISANCE VEHICLE | 30 | | 25 | | | 5 |
| M198 | 155mm HOWITZER | 30 | | 30 | | | |
| M1129 | MOTAR CARRIER | 19 | | | | | 19 |
| M1126 | INFANTRY CARRIER VEHICLE | 70 | 40 | | | | 30 |
| M1128 | MOBILE GUN SYSTEM | 15 | 15 | | | | |
| M1134 | ANTI TANK GUIDED MISSILE | 5 | | | | | 5 |
| M1135 | NBC RECONNAISSANCE VEHICLE | 3 | | | | | 3 |
| M1131 | FIRE SUPPORT VEHICLE | 3 | | | | | 3 |
| M1132 | ENGINEER SUPPORT VEHICLE WITHOUT PLOW | 5 | | 5 | | | |
| M1132/PLOW | JUST THE PLOW | 5 | 5 | | | | |
| M1133 | MEDICAL EVACUATION VEHICLE | 5 | | | | | 5 |
| M998 | CARGO TROOP CARRIER | 67 | | | 18 | 49 | |
| M1044 | ARMAMENT CARRIER/WINCH | 48 | | 17 | 4 | | 27 |
| M149A2 | TRAILER TANK WATER | 25 | | | 25 | | |
| M102 | HIGH MOBILITY 1/4 TON CARGO TRAILER | 25 | | | 25 | | |
| M101 | HIGH MOBILITY 3/4 TON CARGO TRAILER | 25 | | 25 | | | |
| M1083 | DISTRIBUTION COMPANY | 5 | | 5 | | | |
| M978 | DISTRIBUTION COMPANY | 5 | | | | | 5 |
| M911/M747 | DISTRIBUTION COMPANY | 5 | 5 | | | | |

### *3.8.6.2 Area-Volume Report (Sorted by Deck)*

Table 3-12 is a summary report showing the available areas and volumes of the individual decks and levels of the ship.

**Table 3-12 – Summary of Deck/Level Areas and Volumes**

| Deck/Level Description | Area ($Ft.^2$) | Clear Height (Ft.) | Volume ($Ft.^3$) |
|---|---|---|---|
| *O3 Level Accommodations* | 616,887 | 8.5 | 5,243,541 |
| *O2 Level Accommodations* | 768,787 | 8.5 | 6,534,687 |
| *02 Level Bridge* | 312,371 | 8.5 | 2,655,156 |
| *02 Level MMR* | 1,801,752 | 23.5 | 42,341,172 |
| *02 Level Helo Hangar* | 499,944 | 17.0 | 8,499,048 |
| *01 Level* | 5,014,959 | 11.0 | 55,164,551 |
| *Main Deck* | 5,592,280 | 11.5 | 64,311,218 |
| *"B" Deck "A" Hoistable Deck* | 1,789,792 | 12.5 | 22,372,399 |
| *"B" Deck "B" Hoistable Deck* | 1,253,491 | 12.5 | 15,668,640 |
| *"B" Deck (Fwd. Frames 18 - 41)* | 1,789,792 | 24.0 | 42,955,006 |
| *"B" Deck (Aft Frames 55 - 71)* | 1,253,491 | 24.0 | 30,083,790 |
| *"B" Deck AMR 1 (Port)* | 251,145 | 24.0 | 6,027,491 |
| *"B" Deck AMR 1 (Stbd)* | 251,145 | 24.0 | 6,027,491 |
| *"B" Deck AMR 2 (Port)* | 463,339 | 24.0 | 11,120,135 |
| *"B" Deck AMR 2 (Stbd)* | 463,339 | 24.0 | 11,120,135 |
| *"B" Deck AMR 3 (Port)* | 639,672 | 24.0 | 15,352,121 |
| *"B" Deck AMR 3 (Stbd)* | 639,672 | 24.0 | 15,352,121 |
| *"C" Deck (Port)* | 778,048 | 20.9 | 16,261,196 |
| *"C" Deck (Stbd)* | 778,048 | 20.9 | 16,261,196 |
| *"D" Deck Propulsion Machinery (Port)* | 394,227 | 42.5 | 16,754,667 |
| *"D" Deck Propulsion Machinery (Stbd)* | 394,227 | 42.5 | 16,754,667 |
| *"D" Deck Water Jet Propulsor Machinery (Port)* | 307,827 | 12.6 | 3,872,466 |
| *"D" Deck Water Jet Propulsor Machinery (Stbd)* | 307,827 | 12.6 | 3,872,466 |
| **TOTALS:** | 26,362,063 | | 434,605,358 |

## 3.8.7 Recommendations

In arranging the propulsion machinery, it became clear that the demihulls do not have sufficient cross-sectional area to accommodate the propulsion motors that drive the steering and reversing waterjet, and therefore a subsequent design iteration would need to look at changing the shape of the demihulls between frames 71 and 83.

# 3.9 STRUCTURAL DESIGN

## 3.9.1 Design Description

The structural design was initially developed using the design synthesis modeling within ComPASS™. Then the design was further matured to more precisely accommodate the cargo holds, fuel and ballast tanks, machinery and auxiliary spaces, and various other high volume ship compartments. The structural arrangement is provided in detail in the structural drawings.

As part of the design refinement, global hull-girder bending was checked and major structural members at amidships were designed. Conceptual structural scantlings to support the SES cushion end seals and cushion divider were developed.

The structural design description and design data are provided in the following sections.

## 3.9.2 Design Considerations

### *3.9.2.1 Bending Moments*

The Hull-Girder bending moments were computed based on the vessel displacement and loading in the catamaran mode. The Hogging and Sagging bending moments were calculated using the DnV rules; however, the Still-Water bending moment was approximated using a notional weight distribution in the catamaran mode. Figure 3-33 provides the longitudinal distribution of the bending moments used to design the hull structure.

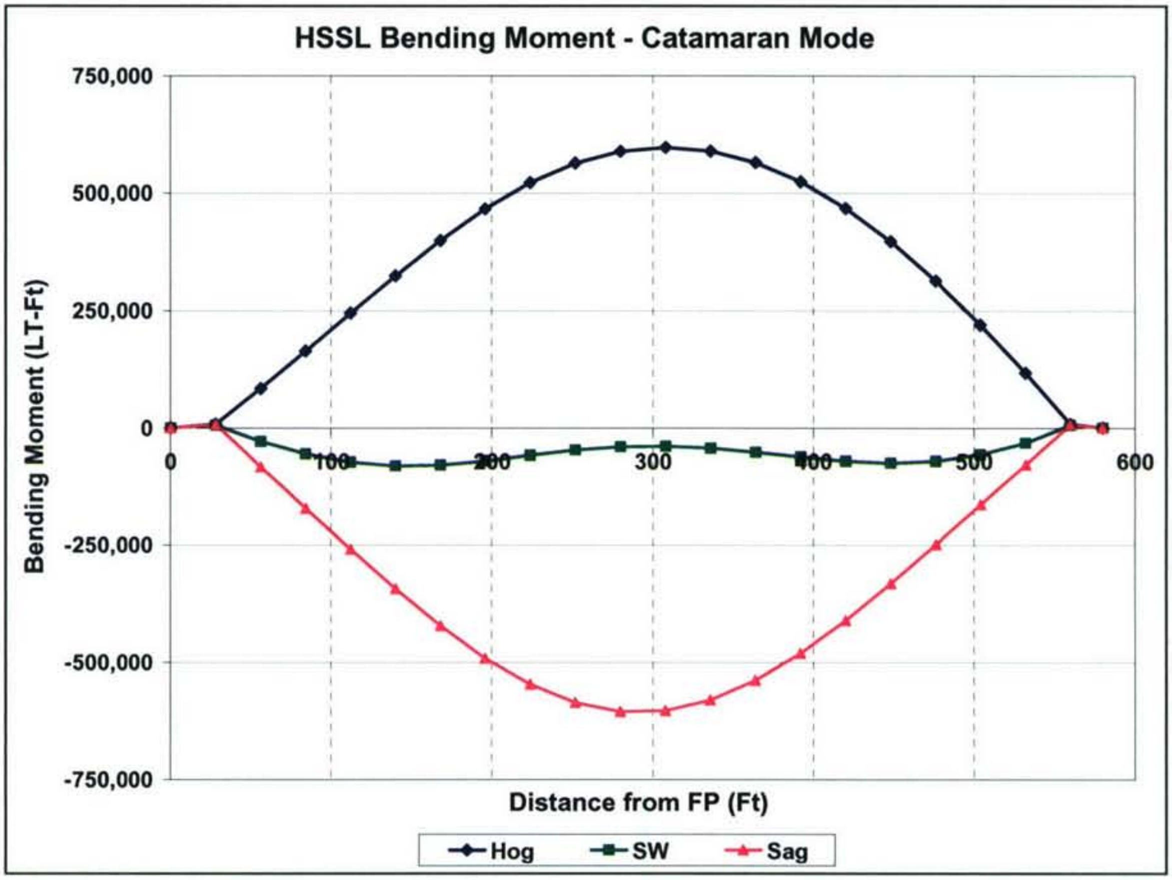


**Figure 3-33 – Hull-Girder Bending Moment Distribution in Catamaran Mode**

### *3.9.2.2 Allowable Stresses*

The material selected for the hull and superstructure was high-strength aluminum alloy, such as AL-5456, which has a welded yield strength of 26-Ksi. In order to provide a design safety margin of 15%, the hull-structure scantlings were designed to 85% of yield strength, i.e. 22.5-Ksi. Table 3-13 provides the material properties and design allowables.

**Table 3-13 – Material Properties**

| | | |
|---|---|---|
| **Grade** | AL-5456 | |
| **Youngs Modulus** | 10,000 | Ksi |
| **Tensile Strength** | 46 | Ksi |
| **Yield Strength** | 33 | Ksi |
| **Yield Strength (Welded)** | 26 | Ksi |
| **Weight Density** | 169 | $lb/ft^3$ |
| **Design Stress Limit** | 22.5 | Ksi |

### *3.9.2.3 Hull-Girder Section*

The hull-girder section properties were designed to keep the global bending stresses below the design stress limit. Table 3-14 provides the hull-girder section properties and design stresses at the mid-ships.

**Table 3-14 – Hull-Girder Section Properties**

| | | |
|---|---|---|
| **Mom-Inertia** | 24,941 | $ft^4$ |
| **Section Modulus @ Keel** | 648.83 | $ft^3$ |
| **Section Modulus @ Deck** | 775.53 | $ft^3$ |
| **Section Area** | 50.32 | $ft^2$ |
| **Design Stress Limit** | 22.5 | Ksi |
| **Max-Stress @ Keel** | 22.4 | Ksi |
| **Max-Stress @ Deck** | 20.6 | Ksi |

## 3.9.3 Structural Scantlings

The structural design was initially based on the structural scantling output from the design synthesis model ComPASS™. Based on the specifics of the cargo hold, machinery spaces and tank arrangement, a notional structural arrangement was then developed to suit the general arrangement of the vessel. The detailed structural arrangements are provided in Appendix A5. Figure A-20 shows the Midship Section structural arrangement, Figure A-21 the arrangement at frames 59 and 67, Figure A-22 the arrangement at frame 79, and finally Figure A-23 shows the arrangement at frames 29 and 43. The scantlings developed from the design synthesis model were revised to accommodate the general arrangement and the notional structural arrangement. The structural scantlings were designed to meet the allowable stress criteria as discussed in the previous section.

Table 3-15 and

Table 3-16 show the typical mid-ship section scantlings. Only the major structural members were identified, and all the secondary and foundation structures are to be designed in subsequent phases of design. The location of the SES-mode cushion end seals and cushion divider were also identified, and the structural scantlings to support those seals and divider were developed.

**Table 3-15 – Midship Section Structural Scantlings**

| Section Name | Plate Tk (in) | Stiffener Scantling (in) |
|---|---|---|
| Bottom Plate 1 | 1.0 | 3x1.25 F / 10x0.625 W |
| Bottom Plate 2 | 1.0 | 3x1.25 F / 10x0.625 W |
| Inner Bottom | 0.75 | 3x1.25 F / 10x0.625 W |
| Side Plate 1 | 0.75 | 3x1.25 F / 10x0.625 W |
| Side Plate 2 | 0.625 | 2.5x1 F / 8x0.5 W |
| Side Plate 3 | 0.5 | 2x0.75 F / 8x0.375 W |
| Sheer Plate | 0.5 | 2x0.75 F / 8x0.375 W |
| Main Deck | 0.625 | 3x0.75 F / 7x0.375 W |
| Deck/Platform | 0.5 | 2.5x0.625 F / 6x0.3125 W |
| House-Top | 0.25 | 4x2x0.25 L |
| Wet Deck | 0.8125 | 2.5x1 F / 8x0.5 W |
| Wet Deck Inbot | 0.625 | 3x0.75 F / 7x0.375 W |
| Wet Deck Girder | 0.8125 | 2.5x1 F / 8x0.5 W |
| BulkHead | 0.6875 | 3x0.75 F / 8x0.375 W |

**Table 3-16 – Midship Section Deep Structural Members**

| Section Name | Scantlings (in) |
|---|---|
| Bottom Girder | 12x2 F / 30x1 W |
| Bottom Web | 8x1.25 F / 24x0.75 W |
| Inner Bot Web | 8x1 F / 22x0.625 W |
| Side Web | 6x0.8125 F / 20x0.5 W |
| Main Deck Girder | 15x2 F / 30x1.25 W |
| Main Deck Beam | 6x1 F / 24x0.5 W |
| Deck/Platform Girder | 10x1.75 F / 24x1 W |
| Deck/Platform Beam | 6x0.75 F / 20x0.4375 W |
| House-Top Girder | 8x1.25 F / 18x0.75 W |
| House-Top Beam | 6x0.5 F / 15x0.375 W |
| Stanchions @ Mn-Dk | 12x12x1 I-Section |
| Stanchions @ 01-Lvl | 10x10x1 I-Section |

## 3.10 Mass Properties

A weight and center of gravity analysis was prepared and maintained in the SWBS format as the ship design developed. This weight report started with an initial baseline weight estimate generated by ComPASS™, which later was populated with higher fidelity data as the ship design matured.

### 3.10.1 Lightship Weight Estimate

The lightship weight estimate was developed at the SWBS two-digit level of detail by using primarily weight estimating relationship data from ComPASS™ based on the "Parent" ship developed during the HSSL Phase I effort. Vendor data for main machinery components, as well as preliminary structural scantlings for decks and shell plating, were used where appropriate to refine the ComPASS™ generated weight estimates. The rolled-up one-digit level lightship estimate, including margins and loads representative of the Full-Load condition, is shown in Table 3-17. The expanded two-digit level Lightship weight estimate is shown in Table 3-20 at the end of this section.

**Table 3-17 – LDS-HSC Weight Report**

| HSSL | LDS-HSC Weight Report | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CURRENT | | VERTICAL | | LONGITUDINAL | | | |
| | | WEIGHT | VCG | MOMENT | LCG | MOMENT | | CLASS | |
| SWBS | DESCRIPTION | (LT) | (ft) ABL | (LT-ft) | (ft) Aft FP | (LT-ft) | E | C | A |
| 1 | HULL STRUCTURE | 3,690.23 | 50.87 | 187711 | 283.43 | 1045916 | 100 | 0 | 0 |
| 2 | PROPULSION | 1,999.94 | 26.65 | 53292 | 433.30 | 866563 | 100 | 0 | 0 |
| 3 | ELECTRIC PLANT | 285.74 | 25.59 | 7312 | 272.72 | 77925 | 100 | 0 | 0 |
| 4 | COMMAND & SURVEILLANCE | 30.00 | 78.06 | 2342 | 280.00 | 8400 | 100 | 0 | 0 |
| 5 | AUXILIARY SYSTEM | 1,936.88 | 40.93 | 79270 | 271.90 | 526646 | 100 | 0 | 0 |
| 6 | OUTFIT & FURNISHINGS | 563.39 | 41.72 | 23507 | 332.23 | 187171 | 100 | 0 | 0 |
| 7 | ARMAMENT | 0.00 | 0.00 | 0 | 280.00 | 0 | 100 | 0 | 0 |
| | LIGHTSHIP | 8,506.17 | 41.55 | 353434 | 318.90 | 2712622 | | | |
| | w/ KG MARGIN | 8,506.17 | 41.55 | 353434 | 318.90 | 2712622 | | | |
| M | WT MARGIN | 850.62 | 41.55 | 35343 | 318.90 | 271262 | 100 | 0 | 0 |
| | LIGHTSHIP WITH MARGIN | 9,356.79 | 41.55 | 388778 | 318.90 | 2983884 | | | |
| F | LOADS | 10,386.34 | 17.54 | 182176 | 229.29 | 2381505 | | | |
| | FULL LOAD TOTAL | 19,743.13 | 29.90 | 590320 | 271.76 | 5365393 | | | |

Additionally, notional longitudinal weight distributions were also developed for each operational mode, two of which, the SES mode and the SWATH mode, are shown graphically in Figure 3-34.

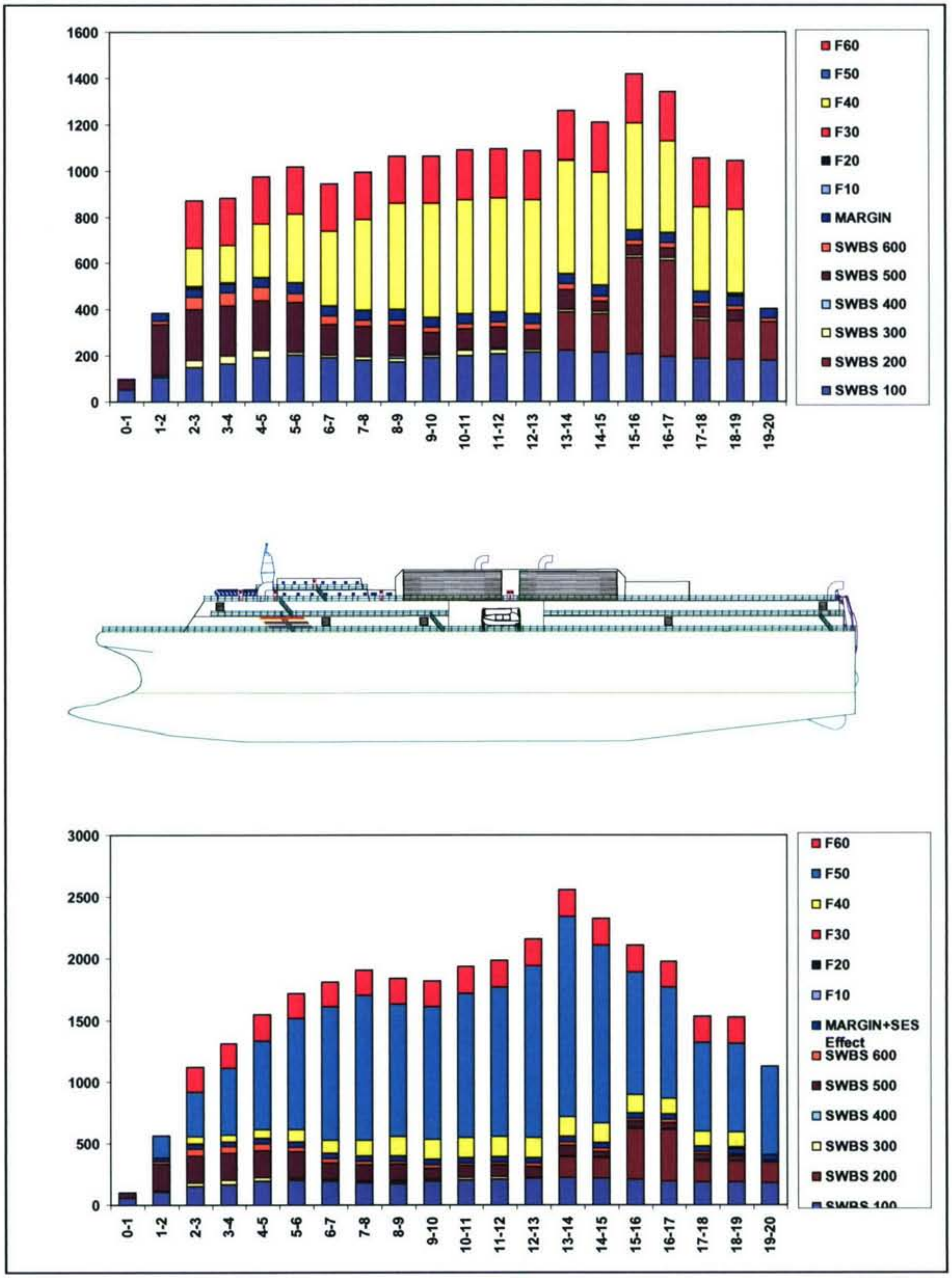


**Figure 3-34 – Longitudinal Weight Distribution in the Catamaran/SES Configuration (top) & the SWATH Configuration (bottom)**

The following sections briefly describe the major elements of the lightship weight estimate.

#### 3.10.1.1 SWBS 100 – Hull Structure

Shell plating and deck weights were estimated using a combination of ComPASS™ data and structural scantling data developed as part of the preliminary structural design. Cushion seal system weight, SWBS 119, was calculated from the CDI SES Design Synthesis Model (SDSM).

#### 3.10.1.2 SWBS 200 – Propulsion

There are six (6) 50 MW propulsion motors, three per demihull, that are assumed to be a future technology upgrade of the existing 36.5 MW High Temperature Superconducting (HTS) motor being developed for ONR by American Superconductor and slated to go on Flight II of the DDG 1000 ship class.

#### 3.10.1.3 SWBS 300 – Electric Plant

The Integrated Power System is represented by six (6) Rolls-Royce MT50 Gas Turbines, two (2) pairs providing power to a 100 MW each TwinPak Generator configuration, and the remaining two (2) powering a single 50 MW Generator each. These are electrically connected to the common Main Electrical Bus that is in turn connected via cabling to six (6) Motor Drives and the Ship Service Power Conversion and Distribution System.

#### 3.10.1.4 SWBS 400 – Command & Surveillance

The weights for this group were estimated based on systems similar to those found on the U.S. Navy's High Speed Vessel HSV-X1.

#### 3.10.1.5 SWBS 500 – Auxiliary Systems

This group is comprised of both ComPASS™ generated weights and an additional weight estimate for the proposed SES Cushion Lift-Air Supply system based on results from SDSM.

#### 3.10.1.6 SWBS 600 – Outfit & Furnishings

The weights for this group were taken directly out of ComPASS™ and are based on a complement of 24.

#### 3.10.1.7 SWBS 700 – Armament

There is no armament presently included in the HSSL LDS-HSC design.

## 3.10.2 Acquisition Margins

Acquisition weight and VCG margins have been set at 10 percent and 5 percent, respectively.

## 3.10.3 Departure Loads

The two primary loads categories are payload and fuel, the departure or full-load details for which are shown in Table 3-18 and Table 3-19.

**Table 3-18 – Payload Weights and Centers**

| Deck: | Weight (LTons) | VCG (Ft-ABL) | VM (Ft-Tons) | LCG (Ft@FP) | LM (Ft-Tons) | TCG (Ft+STB) | TM (Ft-Tons) |
|---|---|---|---|---|---|---|---|
| 01 | 1,411 | 97.20 | 137,110 | 330.48 | 466,177 | 0.100 | 141 |
| Main | 825 | 85.86 | 70,848 | 293.48 | 242,169 | 1.846 | 1,523 |
| Hoistable A | 103 | 71.91 | 7,371 | 189.81 | 19,456 | 0.950 | 97 |
| Hoistable B | 111 | 71.25 | 7,939 | 373.07 | 41,571 | 0.874 | 97 |
| B | 1,151 | 61.72 | 71,063 | 263.90 | 303,834 | 0.744 | 857 |
| Subtotals: | 3,601 | 81.73 | 294,331 | 298.02 | 1,073,208 | 0.754 | 2,716 |

**Table 3-19 – Full-Load Fuel Weights and Centers**

FUEL OIL (98% FULL)    Density: 42.31 ft³/LT

| TANK DESCRIPTION | FRAME LOCATION | % FULL | VOLUME (Ft³) | WEIGHT (L-TONS) | VCG (Ft-ABL) | VMOM (Ft-LT) | LCG (Ft@MP) | LMOM (Ft-LT) | TCG (Ft@STB) | TMOM (Ft-LT) | F-MOM (Ft-LT) "98%" |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-10-1-F | 10-15 | 98% | 6176.30 | 143.06 | 43.18 | 6177 | 201.66 | 28849 | 40.47 | 5790 | 45.2 |
| 2-10-2-F | 10-15 | 98% | 6176.30 | 143.06 | 43.18 | 6177 | 201.66 | 28849 | -40.47 | -5790 | 45.2 |
| 2-15-1-F | 15-20 | 98% | 6880.80 | 159.38 | 43.17 | 6880 | 172.15 | 27437 | 41.05 | 6542 | 59.5 |
| 2-15-2-F | 15-20 | 98% | 6880.80 | 159.38 | 43.17 | 6880 | 172.15 | 27437 | -41.05 | -6542 | 59.5 |
| 2-29-1-F | 29-35 | 98% | 8866.50 | 205.37 | 42.57 | 8743 | 85.23 | 17504 | 41.88 | 8601 | 71.2 |
| 2-29-2-F | 29-35 | 98% | 8866.50 | 205.37 | 42.57 | 8743 | 85.23 | 17504 | -41.88 | -8601 | 71.2 |
| 2-40-1-F | 40-45 | 98% | 7489.30 | 173.47 | 42.48 | 7369 | 22.24 | 3858 | 42.03 | 7291 | 59.4 |
| 2-40-2-F | 40-45 | 98% | 7489.30 | 173.47 | 42.48 | 7369 | 22.24 | 3858 | -42.03 | -7291 | 59.4 |
| 2-45-1-F | 45-50 | 98% | 7522.50 | 174.24 | 42.43 | 7393 | -7.76 | -1352 | 42.13 | 7341 | 59.4 |
| 2-45-2-F | 45-50 | 98% | 7522.50 | 174.24 | 42.43 | 7393 | -7.76 | -1352 | -42.13 | -7341 | 59.4 |
| 2-55-1-F | 55-60 | 98% | 7621.00 | 176.52 | 42.33 | 7472 | -67.78 | -11965 | 42.36 | 7477 | 59.4 |
| 2-55-2-F | 55-60 | 98% | 7621.00 | 176.52 | 42.33 | 7472 | -67.78 | -11965 | -42.36 | -7477 | 59.4 |
| 2-60-1-F | 60-65 | 98% | 7704.10 | 178.45 | 42.24 | 7538 | -97.78 | -17448 | 42.55 | 7593 | 59.4 |
| 2-60-2-F | 60-65 | 98% | 7704.10 | 178.45 | 42.24 | 7538 | -97.78 | -17448 | -42.55 | -7593 | 59.4 |
| 2-79-1-F | 79-83 | 98% | 5376.40 | 124.53 | 43.40 | 5405 | -208.75 | -25996 | 40.86 | 5088 | 47.4 |
| 2-79-2-F | 79-83 | 98% | 5376.40 | 124.53 | 43.40 | 5405 | -208.75 | -25996 | -40.86 | -5088 | 47.4 |
| 2-83-1-F | 83-87 | 98% | 5529.90 | 128.09 | 43.13 | 5524 | -232.69 | -29804 | 41.15 | 5271 | 47.5 |
| 2-83-2-F | 83-87 | 98% | 5529.90 | 128.09 | 43.13 | 5524 | -232.69 | -29804 | -41.15 | -5271 | 47.5 |
| 3-15-1-F | 15-20 | 98% | 21015.30 | 486.76 | 16.57 | 8066 | 172.20 | 83821 | 43.01 | 20936 | 246.3 |
| 3-15-2-F | 15-20 | 98% | 21015.30 | 486.76 | 16.57 | 8066 | 172.20 | 83821 | -43.01 | -20936 | 246.3 |
| 3-29-1-F | 29-35 | 98% | 21981.40 | 509.14 | 20.44 | 10407 | 85.14 | 43348 | 47.20 | 24031 | 853.9 |
| 3-29-2-F | 29-35 | 98% | 21981.40 | 509.14 | 20.44 | 10407 | 85.14 | 43348 | -47.20 | -24031 | 853.9 |
| 3-45-1-F | 45-50 | 98% | 26009.40 | 602.44 | 18.79 | 11320 | -8.20 | -4940 | 50.80 | 30604 | 1195.4 |
| 3-45-2-F | 45-50 | 98% | 26009.40 | 602.44 | 18.79 | 11320 | -8.20 | -4940 | -50.80 | -30604 | 1195.4 |
| 3-79-1-F | 79-83 | 98% | 6085.10 | 140.95 | 22.51 | 3173 | -208.49 | -29386 | 41.27 | 5817 | 78.0 |
| 3-79-2-F | 79-83 | 98% | 6085.10 | 140.95 | 22.51 | 3173 | -208.49 | -29386 | -41.27 | -5817 | 78.0 |
| 3-79-3-F | 79-83 | 98% | 3105.60 | 71.93 | 15.62 | 1124 | -207.73 | -14943 | 57.03 | 4102 | 8.2 |
| 3-79-4-F | 79-83 | 98% | 3105.60 | 71.93 | 15.62 | 1124 | -207.73 | -14943 | -57.03 | -4102 | 8.2 |
| TOTAL FUEL OIL | | | | 6548.63 | 29.50 | 193178 | 21.07 | 137966 | 0.00 | 0 | 5780 |

### 3.10.4 Service Life Allowance

No Service Life Allowance (SLA) weight and KG requirements have been applied for this concept level design study.

Table 3-20 – 2-Digit LDS-HSC Weight Report

| HSSL | LDS-HSC Weight Report - 2 Digit Level | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CURRENT WEIGHT | VCG | VERTICAL MOMENT | LCG | LONGITUDINAL MOMENT | CLASS | | |
| SWBS | DESCRIPTION | (LT) | (ft) ABL | (LT-ft) | (ft) Aft FP | (LT-ft) | E | C | A |
| 1 1 0 | Shell and Supporting Structure | 1,962.67 | 36.52 | 71683 | 280.00 | 549547 | 100 | 0 | 0 |
| 1 2 0 | Hull Structural Bulkheads | 58.24 | 28.41 | 1655 | 280.00 | 16306 | 100 | 0 | 0 |
| 1 3 0 | Hull Decks | 420.62 | 54.02 | 22723 | 280.00 | 117773 | 100 | 0 | 0 |
| 1 4 0 | Hull Platforms and Flats | 235.52 | 36.98 | 8710 | 280.00 | 65946 | 100 | 0 | 0 |
| 1 5 0 | Deck House Structure | 642.74 | 91.32 | 58696 | 280.00 | 179967 | 100 | 0 | 0 |
| 1 6 0 | Special Structures | 18.84 | 28.22 | 532 | 280.00 | 5276 | 100 | 0 | 0 |
| 1 7 0 | Masts, Kingposts, & Service Platforms | 31.48 | 115.56 | 3638 | 280.00 | 8814 | 100 | 0 | 0 |
| 1 8 0 | Foundations | 151.49 | 16.75 | 2537 | 363.50 | 55065 | 100 | 0 | 0 |
| 1 9 0 | Hull Special Purpose Systems | 168.64 | 2.03 | 343 | 280.00 | 47220 | 100 | 0 | 0 |
| | **SUBTOTAL** | **3,690.24** | **46.21** | **170,516.11** | **283.43** | **1,045,914.94** | | | |
| 2 3 0 | Propulsion Units | 221.27 | 10.60 | 2346 | 285.04 | 63071 | 100 | 0 | 0 |
| 2 4 0 | Transmission & Propulsor Systems | 872.97 | 22.24 | 19416 | 496.81 | 433702 | 100 | 0 | 0 |
| 2 5 0 | Propulsion Support Sys. (Non-Fuel & Lub) | 272.89 | 44.61 | 12173 | 283.41 | 77338 | 100 | 0 | 0 |
| 2 6 0 | Propulsion Support System (Fuel & Lub) | 209.62 | 22.76 | 4771 | 281.24 | 58955 | 100 | 0 | 0 |
| 2 9 0 | Propulsion Special Purpose Systems | 423.19 | 34.47 | 14586 | 551.76 | 233498 | 100 | 0 | 0 |
| | **SUBTOTAL** | **1,999.94** | **26.65** | **53,292.17** | **433.30** | **866,563.31** | | | |
| 3 1 0 | Electric Power Generation | 34.06 | 17.04 | 581 | 218.89 | 7455 | 100 | 0 | 0 |
| 3 2 0 | Power Distribution Systems | 161.98 | 26.75 | 4333 | 280.00 | 45354 | 100 | 0 | 0 |
| 3 3 0 | Lighting Systems | 82.16 | 26.75 | 2197 | 280.00 | 23003 | 100 | 0 | 0 |
| 3 4 0 | Power Generation Support Systems | 6.90 | 26.75 | 185 | 280.00 | 1933 | 100 | 0 | 0 |
| 3 9 0 | Electrical Special Purpose Systems | 0.64 | 26.75 | 17 | 280.00 | 179 | 100 | 0 | 0 |
| | **SUBTOTAL** | **285.74** | **25.59** | **7,312.38** | **272.72** | **77,925.08** | | | |
| 5 1 0 | Climate Control Systems | 92.74 | 70.56 | 6543 | 280.00 | 25966 | 100 | 0 | 0 |
| 5 2 0 | Sea Water Systems | 662.90 | 32.32 | 21424 | 280.00 | 185611 | 100 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 3 0 | Fresh Water Systems | 2.31 | 26.75 | 62 | 120.34 | 278 | 100 | 0 | 0 |
| 5 4 0 | Fuels and Lubricants - Handling & Storage | 276.64 | 10.55 | 2919 | 240.68 | 66581 | 100 | 0 | 0 |
| 5 5 0 | Air, Gas & Misc. Fluid Systems | 187.00 | 10.55 | 1973 | 323.64 | 60520 | 100 | 0 | 0 |
| 5 7 0 | Replenishment Systems | 469.15 | 73.56 | 34510 | 275.26 | 129140 | 100 | 0 | 0 |
| 5 8 0 | Mechanical Handling Systems | 103.15 | 65.87 | 6794 | 179.48 | 18513 | 100 | 0 | 0 |
| 5 9 0 | Aux-Sys. Special Purpose Systems | 142.99 | 35.28 | 5045 | 280.00 | 40037 | 100 | 0 | 0 |
| | **SUBTOTAL** | **1,936.88** | **40.93** | **79,270.10** | **271.90** | **526,646.20** | | | |
| | | | | | | | | | |
| 6 1 0 | Ship Fittings | 11.77 | 38.26 | 450 | 319.41 | 3759 | 100 | 0 | 0 |
| 6 2 0 | Hull Compartmentation | 298.54 | 28.78 | 8592 | 381.65 | 113939 | 100 | 0 | 0 |
| 6 3 0 | Preservatives & Coverings | 226.64 | 56.89 | 12894 | 280.00 | 63458 | 100 | 0 | 0 |
| 6 4 0 | Living Spaces | 8.06 | 60.87 | 491 | 256.11 | 2065 | 100 | 0 | 0 |
| 6 5 0 | Service Spaces | 1.14 | 47.04 | 53 | 120.34 | 137 | 100 | 0 | 0 |
| 6 6 0 | Working Spaces | 11.31 | 62.99 | 712 | 192.70 | 2178 | 100 | 0 | 0 |
| 6 7 0 | Stowage Spaces | 5.70 | 52.92 | 302 | 275.26 | 1570 | 100 | 0 | 0 |
| 6 9 0 | O&F Special Purpose Systems | 0.24 | 52.92 | 12 | 280.00 | 66 | 100 | 0 | 0 |
| | **SUBTOTAL** | **563.39** | **41.72** | **23,506.80** | **332.23** | **187,171.46** | | | |

## 3.11 Stability

### 3.11.1 Design Description

This section demonstrates that the ship design meets the ABS High Speed Naval Craft (HSNC) intact stability and preliminary reserve buoyancy requirements throughout its operating weight range. The analysis sought to define the limits on draft, GM and trim, and includes the calculations required to support their values in conjunction with aerostatic assistance from the SES air cushion.

### 3.11.2 Design Considerations

The criteria used to determine the limiting draft and intact stability for beam winds was obtained from the IMO 2000 HSC (High-Speed Craft) Code, which are the regulations that the ABS High Speed Naval Craft rules defer to.

The requirements for ballasting down were set by the aerostatic lift necessary to achieve the SWATH waterline, which is set at 44 feet. Given the Hybrid nature of this design, no specific requirements exist that set forth a minimum GM for intact stability while ballasting down; therefore, CDIM sought to define this criteria based on data from past design analyses of similar vessel types. Specifically, a report entitled "*SWATH Concept: Designing Superior Operability into a Surface Displacement Ship*" was consulted. The report states that "for purposes of completed feasibility design studies, acceptable stability is defined as a transverse metacentric height ($GM_T$) of at least 3.5 Ft and a minimum longitudinal metacentric height ($GM_L$) of 10 percent of the ship length", or 58 Ft in the case of the HSSL design.

### 3.11.3 Floodable Length

A floodable length curve is traditionally used when determining longitudinal subdivision. At any point along the length of the ship, the floodable length curve provides the maximum length of damage (centered at the point of damage) that the ship is capable of sustaining without submergence of the margin line. This calculation also is a preliminary check to insure that the vessel has sufficient reserve buoyancy after damage.

Figure A-1 in Appendix A1 presents the floodable length curve as calculated for the HSSL hullform with three compartment permeabilities. These permeability curves were used to determine the major watertight subdivision of the ship, resulting in main watertight bulkheads at frames 10, 29, 55 and 71, which extend from the baseline to the main deck or bulkhead deck.

### 3.11.4 Trim & Intact Stability

The following Trim and Stability output represents the ship in its three modes of operation and demonstrates that there is adequate intact transverse and longitudinal GM

to meet the requirements set forth in the ABS rules as well as the suggested design guidelines of Ref 4. Based on these outputs, the conclusion can be drawn that the SWATH mode will represent the limiting case for damage stability given that the transverse GM for this case is 3.66 feet, only a tenth of a foot above the suggested minimum value of 3.5 feet.

**CONDITION:** FULL LOAD - DEPARTURE
**MODE:** CATAMARAN

SUMMARY OF LOADS

| ITEM | WEIGHT (Ltons) | VCG (ft-ABL) | VMOM (ft-Lton) | LCG (ft-Aft of FP) | LMOM (ft-Lton) | TCG (ft +STBD) | TMOM (ft-Lton) | F-Corr (ft-Lton) |
|---|---|---|---|---|---|---|---|---|
| LIGHTSHIP | 8506.17 | 41.55 | 353431 | 318.90 | 2712618 | 0.00 | 0 | 0 |
| CREW & STORES | 3.50 | 85.00 | 298 | 144.90 | 507 | 0.00 | 0 | 0 |
| Cargo: 01 Deck | 1410.63 | 97.20 | 137110 | 330.48 | 466177 | 0.10 | 141 | 0 |
| Cargo: Main Deck | 825.18 | 85.86 | 70848 | 293.48 | 242169 | 1.85 | 1523 | 0 |
| Cargo: Hoistable A Deck | 102.50 | 71.91 | 7371 | 189.81 | 19456 | 0.95 | 97 | 0 |
| Cargo: Hoistable B Deck | 111.43 | 71.25 | 7939 | 373.07 | 41571 | 0.87 | 97 | 0 |
| Cargo: B Deck | 1151.34 | 61.72 | 71063 | 263.90 | 303834 | 0.74 | 857 | 0 |
| CARGO SUBTOTAL | 3601.07 | 81.73 | 294331 | 298.02 | 1073208 | 0.75 | 2716 | 0 |
| RAPID BALLAST | 0.00 | 0.00 | 0 | 277.25 | 0 | 0.00 | 0 | 0 |
| REGULAR BALLAST | 0.00 | 0.00 | 0 | 277.25 | 0 | 0.00 | 0 | 0 |
| FUEL OIL | 6548.63 | 29.50 | 193178 | 256.18 | 1677643 | 0.00 | 0 | 5780 |
| MISSION RELATED | 24.55 | 17.40 | 427 | 304.30 | 7471 | 0.00 | 0 | 0 |
| MISCELLANEOUS | 1.60 | 9.17 | 15 | 296.70 | 475 | 0.00 | 0 | 0 |
| MARGINS | 850.62 | 43.63 | 37113 | 318.90 | 271263 | 0.00 | 0 | 0 |
| TOTALS: | 19536.14 | 44.98 | 878792.66 | 293.98 | 5743182.91 | 0.14 | 2716.43 | 5780 |

**STABILITY CALCULATION**

| | | | |
|---|---|---|---|
| A. | MEAN SW DRAFT | 28.61 | (ft) |
| B. | KMt | 124.28 | (ft) |
| C. | KG | 44.98 | (ft) |
| D. | F.S. Correction | 0.30 | (ft) |
| E. | KG Corrected (C+ D) | 45.28 | (ft) |
| F. | KG Allowable | 0.00 | (ft) |
| G. | GMt Available (B - E) | 79.00 | (ft) |
| | GMl (≥ 10% LOA) | 733.34 | (ft) |
| H. | LCG (Aft of F.P.) | 293.98 | (ft) |
| I. | LCB (Aft of F.P.) | 296.04 | (ft) |

**TRIM/DRAFT CALCULATION**

| | | | | |
|---|---|---|---|---|
| J. | TRIM LEVER (H - I) | | -2.06 | (ft) |
| K. | MOMENT TO TRIM 1" | | 2189.96 | (ft-Lton) |
| L. | TRIM (+ Aft) | (DISPL.) x J / K x 12 | -1.53 | (ft) |
| M. | LCF (Aft of F.P.) | | 328.42 | (ft) |
| N. | DRAFT F.P. | A - L x M / 560 | 29.51 | (ft) |
| O. | DRAFT A.P. | (N + L) | 27.98 | (ft) |
| P. | DRAFT M.P. | (N + O) / 2 | 28.74 | (ft) |

**CONDITION:** FULL LOAD - ARRIVAL
**MODE:** SWATH w/o SES

| ITEM | WEIGHT (Ltons) | VCG (ft-ABL) | VMOM (ft-Lton) | LCG (ft-Aft of FP) | LMOM (ft-Lton) | TCG (ft +STBD) | TMOM (ft-Lton) | F-Corr (ft-Lton) |
|---|---|---|---|---|---|---|---|---|
| | SUMMARY OF LOADS | | | | | | | |
| LIGHTSHIP | 8506.17 | 41.55 | 353431 | 318.90 | 2712618 | 0.00 | 0 | 0 |
| CREW & STORES | 3.50 | 85.00 | 298 | 144.90 | 507 | 0.00 | 0 | 0 |
| Cargo: 01 Deck | 1410.63 | 97.20 | 137110 | 330.48 | 466177 | 0.10 | 141 | 0 |
| Cargo: Main Deck | 825.18 | 85.86 | 70848 | 293.48 | 242169 | 1.85 | 1523 | 0 |
| Cargo: Hoistable A Deck | 102.50 | 71.91 | 7371 | 189.81 | 19456 | 0.95 | 97 | 0 |
| Cargo: Hoistable B Deck | 111.43 | 71.25 | 7939 | 373.07 | 41571 | 0.87 | 97 | 0 |
| Cargo: B Deck | 1151.34 | 61.72 | 71063 | 263.90 | 303834 | 0.74 | 857 | 0 |
| CARGO SUBTOTAL | 3601.07 | 81.73 | 294331 | 298.02 | 1073208 | 0.75 | 2716 | 0 |
| RAPID BALLAST | 7655.74 | 18.11 | 138682 | 328.92 | 2518152 | 0.00 | 0 | 0 |
| REGULAR BALLAST | 0.00 | 0.00 | 0 | 277.25 | 0 | 0.00 | 0 | 0 |
| FUEL OIL | 6548.63 | 29.50 | 193178 | 256.18 | 1677643 | 0.00 | 0 | 5780 |
| MISSION RELATED | 24.55 | 17.40 | 427 | 304.30 | 7471 | 0.00 | 0 | 0 |
| MISCELLANEOUS | 1.60 | 9.17 | 15 | 296.70 | 475 | 0.00 | 0 | 0 |
| MARGINS | 850.62 | 43.63 | 37113 | 318.90 | 271263 | 0.00 | 0 | 0 |
| SES System Effect | 0.00 | 36.65 | 0 | 304.00 | 0 | 0.00 | 0 | 0 |
| TOTALS: | 27192 | 37.42 | 1017475 | 303.82 | 8261335 | 0.10 | 2716.43 | 5780 |

**STABILITY CALCULATION**

| | | | |
|---|---|---|---|
| *A.* | MEAN SW DRAFT | *43.99* | (ft) |
| *B.* | KMt | *41.29* | (ft) |
| *C.* | KG | *37.42* | (ft) |
| *D.* | F.S. Correction | *0.21* | (ft) |
| *E.* | $KG_{Corrected}$ (*C* + *D*) | *37.63* | (ft) |
| *F.* | $KG_{Allowable}$ | *0.00* | (ft) |
| *G.* | $GMt_{Available}$ (*B* - *E*) | *3.66* | (ft) |
| | GMl (≥ 10% LOA) | *226.30* | (ft) |
| *H.* | LCG (Aft of F.P.) | *303.82* | (ft) |
| *I.* | LCB (Aft of F.P.) | *303.82* | (ft) |

**TRIM/DRAFT CALCULATION**

| | | | | |
|---|---|---|---|---|
| *J.* | TRIM LEVER (*H* - *I*) | | *-0.01* | (ft) |
| *K.* | MOMENT TO TRIM 1" | | *945.22* | (ft-Lton) |
| *L.* | TRIM (+ Aft) | $\frac{(DISPL.) \times J}{K \times 12}$ | *-0.02* | (ft) |
| *M.* | LCF (Aft of F.P.) | | *307.17* | (ft) |
| *N.* | DRAFT F.P. | $\frac{A - L \times M}{560}$ | *44.00* | (ft) |
| *O.* | DRAFT A.P. | $(N + L)$ | *43.98* | (ft) |
| *P.* | DRAFT M.P. | $\frac{(N + O)}{2}$ | *43.99* | (ft) |

**CONDITION: FULL LOAD - ARRIVAL**
**MODE: SES**

| ITEM | SUMMARY OF LOADS WEIGHT (Ltons) | VCG (ft-ABL) | VMOM (ft-Lton) | LCG (ft-Aft of FP) | LMOM (ft-Lton) | TCG (ft +STBD) | TMOM (ft-Lton) | F-Corr (ft-Lton) |
|---|---|---|---|---|---|---|---|---|
| LIGHTSHIP | 8506.17 | 41.55 | 353431 | 318.90 | 2712618 | 0.00 | 0 | 0 |
| CREW & STORES | 3.50 | 85.00 | 298 | 144.90 | 507 | 0.00 | 0 | 0 |
| Cargo: 01 Deck | 1410.63 | 97.20 | 137110 | 330.48 | 466177 | 0.10 | 141 | 0 |
| Cargo: Main Deck | 825.18 | 85.86 | 70848 | 293.48 | 242169 | 1.85 | 1523 | 0 |
| Cargo: Hoistable A Deck | 102.50 | 71.91 | 7371 | 189.81 | 19456 | 0.95 | 97 | 0 |
| Cargo: Hoistable B Deck | 111.43 | 71.25 | 7939 | 373.07 | 41571 | 0.87 | 97 | 0 |
| Cargo: B Deck | 1151.34 | 61.72 | 71063 | 263.90 | 303834 | 0.74 | 857 | 0 |
| CARGO SUBTOTAL | 3601.07 | 81.73 | 294331 | 298.02 | 1073208 | 0.75 | 2716 | 0 |
| RAPID BALLAST | 0.00 | 0.00 | 0 | 277.25 | 0 | 0.00 | 0 | 0 |
| REGULAR BALLAST | 0.00 | 0.00 | 0 | 277.25 | 0 | 0.00 | 0 | 0 |
| FUEL OIL | 2220.51 | 21.70 | 48182 | 137.84 | 306078 | 0.00 | 0 | 5780 |
| MISSION RELATED | 24.55 | 17.40 | 427 | 304.30 | 7471 | 0.00 | 0 | 0 |
| MISCELLANEOUS | 1.60 | 9.17 | 15 | 296.70 | 475 | 0.00 | 0 | 0 |
| MARGINS | 850.62 | 43.63 | 37113 | 318.90 | 271263 | 0.00 | 0 | 0 |
| SES System Effect | -1810.00 | 50.74 | -91839 | 341.00 | -617210 | 0.00 | 0 | 0 |
| TOTALS: | 13398 | 47.91 | 641957 | 280.22 | 3754409 | 0.20 | 2716.43 | 5780 |

**STABILITY CALCULATION**

| | | | |
|---|---|---|---|
| A. | MEAN SW DRAFT | *21.52* | (ft) |
| B. | KMt | *190.14* | (ft) |
| C. | KG | *47.91* | (ft) |
| D. | F.S. Correction | *0.43* | (ft) |
| E. | KG $_{Corrected}$ (C+ D) | *48.35* | (ft) |
| F. | KG $_{Allowable}$ | *0.00* | (ft) |
| G. | GMt $_{Available}$ (B - E) | *141.80* | (ft) |
| | GMl (≥ 10% LOA) | *1425.49* | (ft) |
| H. | LCG (Aft of F.P.) | *280.22* | (ft) |
| I. | LCB (Aft of F.P.) | *288.82* | (ft) |

**TRIM/DRAFT CALCULATION**

| | | | | |
|---|---|---|---|---|
| J. | TRIM LEVER (H - I) | | *-8.60* | (ft) |
| K. | MOMENT TO TRIM 1" | | *2796.17* | (ft-Lton) |
| L. | TRIM (+ Aft) | $\frac{(DISPL.) \times J}{K \times 12}$ | *-3.43* | (ft) |
| M. | LCF (Aft of F.P.) | | *304.08* | (ft) |
| N. | DRAFT F.P. | $\frac{A - L \times M}{560}$ | *23.38* | (ft) |
| O. | DRAFT A.P. | (N + L) | *19.95* | (ft) |
| P. | DRAFT M.P. | $\frac{(N + O)}{2}$ | *21.67* | (ft) |

## 3.11.5 Ballast Polygon

When designing vessels that require a substantial amount of ballast in order to be able to attain certain operational drafts and trim angles, it is typical early on in the design process to use a Ballast Polygon to determine whether adequate ballast is available and located such that it can provide the full range of operating draft and trim to meet the operating requirements. The polygon shown in Figure 3-35 indicates that the current design has sufficient ballast to be able to meet the SWATH mode draft in a MINOP condition; however, a redistribution of fuel and ballast needs to be performed to shift the amount of existing ballast so that it is more balanced about the ship's mid perpendicular. This

redistribution is sought so that the MINOP points that are plotted along with the polygon come to lie inside the polygon and not outside of it as is currently the case. This needs to be performed following a further evolution of the weights and centers, when there is a higher degree of confidence that the lightship weight is closer to what would constitute that of a preliminary design.

On Amphibious ships, it is typical practice to locate Rapid Ballast tanks in the double-bottom area where they would have shell-to-shell transverse extents so that, during the rapid filling process, there is no likelihood of off-center moments arising from an asymmetric tank fill. Given the geometry of this vessel, that is unfortunately not possible and therefore tank pairs need to be filled in unison.

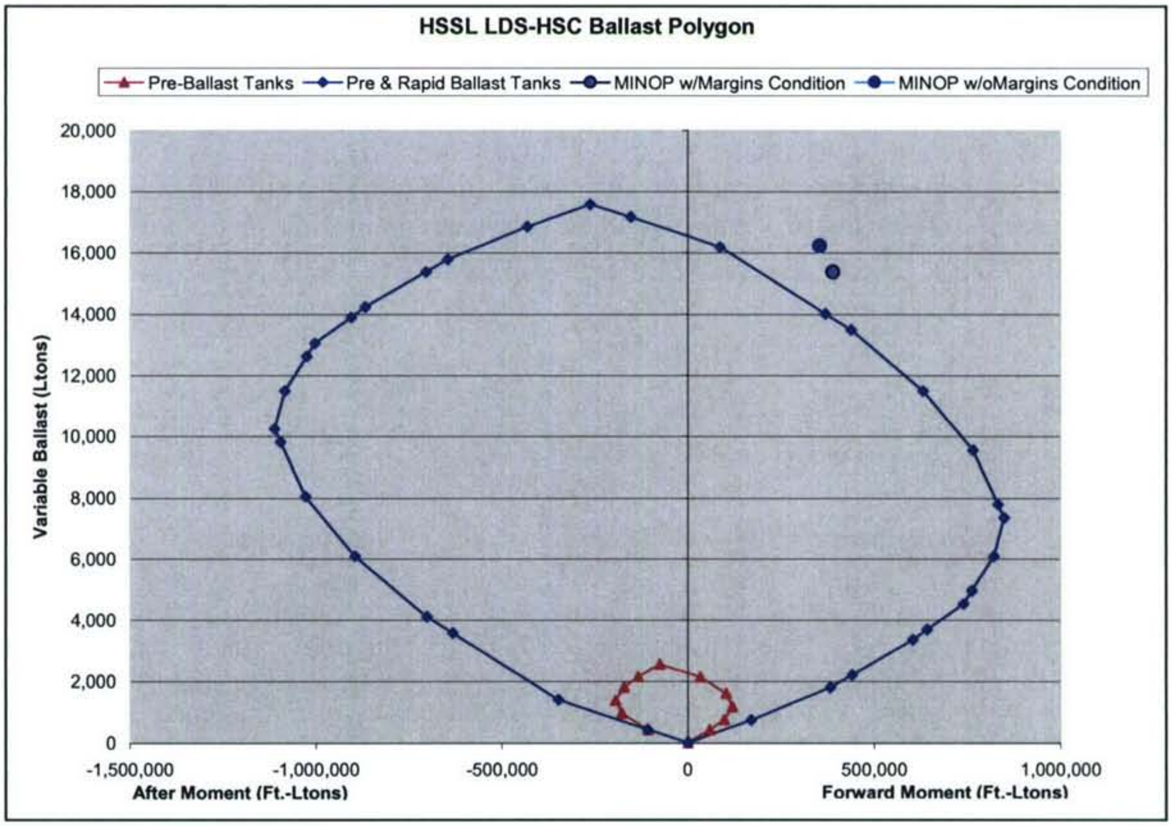


**Figure 3-35 – HSSL Ballast Polygon**

### 3.11.6 Recommendations for Future Study

Based on the current weight estimates, it appears that when the vessel is operating in either the Catamaran or SES modes, the GM may be excessive. As the design evolves, this excess GM will likely disappear, but it should be monitored closely as it could lead to a very stiff and therefore unfriendly ship to ride on.

A full up damaged stability analysis, used to determine an Allowable KG and limiting displacement/draft curve, needs to be performed. This type of analysis should be carried

out following further refinement of the weights, which seeks to replace many of the initial ComPASS™ estimates with values based on the actual design.

Another area that will need further refinement is the allocation or redistribution of ballast and fuel. The ballast polygon confirms that the current design does have sufficient ballast tankage to achieve the SWATH ballasted down draft in both the MINOP condition with and without margins, but that the ballast needs to be redistributed. Also, based on the model tests of this concept conducted at DTMB in December 2006, it was determined that:

1. achieving the 6.5 M draft goal was easily accomplished with assistance from the SES cushion, implying that not so much lift is required from the cushion and therefore not so much ballast would need to be taken on board to achieve the SWATH mode of operation.
2. the SWATH mode of operation without SES motion control resulted in very significantly reduced motions in sea states 5 & 6. This may be sufficient to allow safe transfer of cargo from the Sea Base to the HSSL without the need for SES motion control, which would significantly reduce the amount of ballast needed as it would be equal to the weight otherwise supported by the SES cushion.

### 3.11.7 Supporting Calculations

The following sections address some of the calculations that were performed in support of the stability analysis.

#### *3.11.7.1 Hydrostatics*

Given that much of the hullform fairing was performed using the Rhino NURBS surface modeling software, the hydrostatics for this hullform were initially determined using the RhinoMarine software module. Since the hullform was subsequently translated into a GHS compatible geometry file for purposes of developing floodable length and tankage calculations, a set of hydrostatics were also generated using GHS. These were checked and found to be within 2% of those values calculated by RhinoMarine.

The table of Hydrostatics is provided in Appendix B.

#### *3.11.7.2 Tankage*

Given the 43-knot speed and 5000 nautical mile range requirements, it should come as no surprise that this ship must be able to accommodate a substantial amount of fuel. As already mentioned, due to the unique hybrid hullform with the ability to transform itself from catamaran to SES to SWATH, there is the added requirement to be able to ballast the ship through a wide range of drafts and trims, therefore necessitating additional volume for tankage. The fuel and ballast were arranged in such a way as to help maintain the ship at close to an even keel while the fuel is being burned during transit. This is

especially critical for this highly optimized hullform, which has the best reduced drag performance and therefore is most efficient when operating around its design waterline.

The tank capacity tables for fuel and ballast are provided in Table 3-21, Table 3-22 and Table 3-23 on the following pages.

## Table 3-21 – Fuel Tank Capacities

FUEL OIL (98% FULL)

Density: 42.31 $ft^3/LT$

| TANK DESCRIPTION | FRAME LOCATION | % FULL | VOLUME ($Ft^3$) | WEIGHT (L-TONS) | VCG (Ft-ABL) | VMOM (Ft-LT) | LCG (Ft@MP) | LMOM (Ft-LT) | TCG (Ft@STB) | TMOM (Ft-LT) | F-MOM (Ft-LT) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-10-1-F | 10-15 | 98% | 6176.30 | 143.06 | 43.18 | 6177 | 201.66 | 28849 | 40.47 | 5790 | 45.2 |
| 2-10-2-F | 10-15 | 98% | 6176.30 | 143.06 | 43.18 | 6177 | 201.66 | 28849 | -40.47 | -5790 | 45.2 |
| 2-15-1-F | 15-20 | 98% | 6880.80 | 159.38 | 43.17 | 6880 | 172.15 | 27437 | 41.05 | 6542 | 59.5 |
| 2-15-2-F | 15-20 | 98% | 6880.80 | 159.38 | 43.17 | 6880 | 172.15 | 27437 | -41.05 | -6542 | 59.5 |
| 2-29-1-F | 29-35 | 98% | 8866.50 | 205.37 | 42.57 | 8743 | 85.23 | 17504 | 41.88 | 8601 | 71.2 |
| 2-29-2-F | 29-35 | 98% | 8866.50 | 205.37 | 42.57 | 8743 | 85.23 | 17504 | -41.88 | -8601 | 71.2 |
| 2-40-1-F | 40-45 | 98% | 7489.30 | 173.47 | 42.48 | 7369 | 22.24 | 3858 | 42.03 | 7291 | 59.4 |
| 2-40-2-F | 40-45 | 98% | 7489.30 | 173.47 | 42.48 | 7369 | 22.24 | 3858 | -42.03 | -7291 | 59.4 |
| 2-45-1-F | 45-50 | 98% | 7522.50 | 174.24 | 42.43 | 7393 | -7.76 | -1352 | 42.13 | 7341 | 59.4 |
| 2-45-2-F | 45-50 | 98% | 7522.50 | 174.24 | 42.43 | 7393 | -7.76 | -1352 | -42.13 | -7341 | 59.4 |
| 2-55-1-F | 55-60 | 98% | 7621.00 | 176.52 | 42.33 | 7472 | -67.78 | -11965 | 42.36 | 7477 | 59.4 |
| 2-55-2-F | 55-60 | 98% | 7621.00 | 176.52 | 42.33 | 7472 | -67.78 | -11965 | -42.36 | -7477 | 59.4 |
| 2-60-1-F | 60-65 | 98% | 7704.10 | 178.45 | 42.24 | 7538 | -97.78 | -17448 | 42.55 | 7593 | 59.4 |
| 2-60-2-F | 60-65 | 98% | 7704.10 | 178.45 | 42.24 | 7538 | -97.78 | -17448 | -42.55 | -7593 | 59.4 |
| 2-79-1-F | 79-83 | 98% | 5376.40 | 124.53 | 43.40 | 5405 | -208.75 | -25996 | 40.86 | 5088 | 47.4 |
| 2-79-2-F | 79-83 | 98% | 5376.40 | 124.53 | 43.40 | 5405 | -208.75 | -25996 | -40.86 | -5088 | 47.4 |
| 2-83-1-F | 83-87 | 98% | 5529.90 | 128.09 | 43.13 | 5524 | -232.69 | -29804 | 41.15 | 5271 | 47.5 |
| 2-83-2-F | 83-87 | 98% | 5529.90 | 128.09 | 43.13 | 5524 | -232.69 | -29804 | -41.15 | -5271 | 47.5 |
| 3-15-1-F | 15-20 | 98% | 21015.30 | 486.76 | 16.57 | 8066 | 172.20 | 83821 | 43.01 | 20936 | 246.3 |
| 3-15-2-F | 15-20 | 98% | 21015.30 | 486.76 | 16.57 | 8066 | 172.20 | 83821 | -43.01 | -20936 | 246.3 |
| 3-29-1-F | 29-35 | 98% | 21981.40 | 509.14 | 20.44 | 10407 | 85.14 | 43348 | 47.20 | 24031 | 853.9 |
| 3-29-2-F | 29-35 | 98% | 21981.40 | 509.14 | 20.44 | 10407 | 85.14 | 43348 | -47.20 | -24031 | 853.9 |
| 3-45-1-F | 45-50 | 98% | 26009.40 | 602.44 | 18.79 | 11320 | -8.20 | -4940 | 50.80 | 30604 | 1195.4 |
| 3-45-2-F | 45-50 | 98% | 26009.40 | 602.44 | 18.79 | 11320 | -8.20 | -4940 | -50.80 | -30604 | 1195.4 |
| 3-79-1-F | 79-83 | 98% | 6085.10 | 140.95 | 22.51 | 3173 | -208.49 | -29386 | 41.27 | 5817 | 78.0 |
| 3-79-2-F | 79-83 | 98% | 6085.10 | 140.95 | 22.51 | 3173 | -208.49 | -29386 | -41.27 | -5817 | 78.0 |
| 3-79-3-F | 79-83 | 98% | 3105.60 | 71.93 | 15.62 | 1124 | -207.73 | -14943 | 57.03 | 4102 | 8.2 |
| 3-79-4-F | 79-83 | 98% | 3105.60 | 71.93 | 15.62 | 1124 | -207.73 | -14943 | -57.03 | -4102 | 8.2 |
| TOTAL FUEL OIL | | | | 6548.63 | 29.50 | 193178 | 21.07 | 137966 | 0.00 | 0 | 5780 |

**Table 3-22 – Rapid Ballast Capacities**

| TANK DESCRIPTION | FRAME LOCATION | % FULL | VOLUME ($Ft^3$) | WEIGHT (LTONS) | VCG (Ft-ABL) | VMOM (Ft-LT) | LCG (Ft@MP) | LMOM (Ft-LT) | TCG (Ft+STB) | TMOM (Ft-LT) | F-MOM (Ft-LT) "SLACK" |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3-5-1-W | 6-10 | 100% | 12831.70 | 366.55 | 18.86 | 6913 | 230.94 | 84652 | 41.03 | 15040 | 0 |
| 3-5-2-W | 6-10 | 100% | 12831.70 | 366.55 | 18.86 | 6913 | 230.94 | 84652 | -41.03 | -15040 | 0 |
| 3-10-1-W | 10-15 | 100% | 18572.90 | 530.56 | 17.23 | 9141 | 201.64 | 106981 | 42.03 | 22299 | 0 |
| 3-10-2-W | 10-15 | 100% | 18572.90 | 530.56 | 17.23 | 9141 | 201.64 | 106981 | -42.03 | -22299 | 0 |
| 3-20-1-W | 20-25 | 100% | 20037.30 | 572.39 | 18.17 | 10400 | 142.49 | 81560 | 44.53 | 25488 | 0 |
| 3-20-2-W | 20-25 | 100% | 20037.30 | 572.39 | 18.17 | 10400 | 142.49 | 81560 | -44.53 | -25488 | 0 |
| 3-25-1-W | 25-29 | 100% | 14803.30 | 422.87 | 19.74 | 8348 | 115.34 | 48774 | 45.96 | 19435 | 0 |
| 3-25-2-W | 25-29 | 100% | 14803.30 | 422.87 | 19.74 | 8348 | 115.34 | 48774 | -45.96 | -19435 | 0 |
| 3-35-1-W | 35-40 | 100% | 19672.30 | 561.96 | 20.84 | 11711 | 52.01 | 29228 | 48.36 | 27177 | 0 |
| 3-35-2-W | 35-40 | 100% | 19672.30 | 561.96 | 20.84 | 11711 | 52.01 | 29228 | -48.36 | -27177 | 0 |
| 3-40-1-W | 40-45 | 100% | 22113.10 | 631.69 | 20.27 | 12804 | 21.90 | 13834 | 49.48 | 31256 | 0 |
| 3-40-2-W | 40-45 | 100% | 22113.10 | 631.69 | 20.27 | 12804 | 21.90 | 13834 | -49.48 | -31256 | 0 |
| 3-50-1-W | 50-55 | 100% | 30817.50 | 880.34 | 17.71 | 15591 | -38.12 | -33558 | 52.04 | 45813 | 0 |
| 3-50-2-W | 50-55 | 100% | 30817.50 | 880.34 | 17.71 | 15591 | -38.12 | -33558 | -52.04 | -45813 | 0 |
| 3-55-1-W | 55-60 | 100% | 34309.60 | 980.09 | 17.11 | 16769 | -67.85 | -66499 | 52.98 | 51925 | 0 |
| 3-55-2-W | 55-60 | 100% | 34309.60 | 980.09 | 17.11 | 16769 | -67.85 | -66499 | -52.98 | -51925 | 0 |
| 3-60-1-W | 60-65 | 100% | 34672.00 | 990.45 | 17.40 | 17234 | -97.70 | -96767 | 53.30 | 52791 | 0 |
| 3-60-2-W | 60-65 | 100% | 34672.00 | 990.45 | 17.40 | 17234 | -97.70 | -96767 | -53.30 | -52791 | 0 |
| 3-65-1-W | 65-71 | 100% | 38015.80 | 1085.97 | 18.52 | 20112 | -130.31 | -141512 | 52.98 | 57534 | 0 |
| 3-65-2-W | 65-71 | 100% | 38015.80 | 1085.97 | 18.52 | 20112 | -130.31 | -141512 | -52.98 | -57534 | 0 |
| 3-83-1-W | 83-AP | 100% | 17098.40 | 488.44 | 24.95 | 12186 | -245.60 | -119960 | 49.48 | 24168 | 0 |
| 3-83-2-W | 83-AP | 100% | 17098.40 | 488.44 | 24.95 | 12186 | -245.60 | -119960 | -49.48 | -24168 | 0 |
| TOTAL RAPID BALLAST | | | | 15022.60 | 18.80 | 282421 | -12.42 | -186536 | 0.00 | 0 | 0 |

## Table 3-23 – Pre-Ballast Capacities

SW REGULAR BALLAST (100% FULL)

Density: 35.01 $ft^3/LT$

| TANK DESCRIPTION | FRAME LOCATION | % FULL | VOLUME ($Ft^3$) | WEIGHT (LTONS) | VCG (Ft-ABL) | VMOM (Ft-LT) | LCG (Ft@MP) | LMOM (Ft-LT) | TCG (Ft+STB) | TMOM (Ft-LT) | F-MOM (Ft-LT) "SLACK" |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-20-1-W | 24-30 | 100% | 7139.30 | 203.94 | 43.10 | 8790 | 142.16 | 28992 | 41.37 | 8437 | 0.0 |
| 2-20-2-W | 24-30 | 100% | 7139.30 | 203.94 | 43.10 | 8790 | 142.16 | 28992 | -41.37 | -8437 | 0.0 |
| 2-25-1-W | 25-29 | 100% | 5852.30 | 167.18 | 42.90 | 7172 | 115.23 | 19264 | 41.67 | 6966 | 0.0 |
| 2-25-2-W | 25-29 | 100% | 5852.30 | 167.18 | 42.90 | 7172 | 115.23 | 19264 | -41.67 | -6966 | 0.0 |
| 2-35-1-W | 35-40 | 100% | 7439.60 | 212.52 | 42.76 | 9087 | 52.23 | 11100 | 41.92 | 8909 | 0.0 |
| 2-35-2-W | 35-40 | 100% | 7439.60 | 212.52 | 42.76 | 9087 | 52.23 | 11100 | -41.92 | -8909 | 0.0 |
| 2-50-1-W | 50-55 | 100% | 7557.50 | 215.89 | 42.63 | 9203 | -37.77 | -8154 | 42.18 | 9106 | 0.0 |
| 2-50-2-W | 50-55 | 100% | 7557.50 | 215.89 | 42.63 | 9203 | -37.77 | -8154 | -42.18 | -9106 | 0.0 |
| 2-65-1-W | 65-71 | 100% | 9317.90 | 266.18 | 42.42 | 11291 | -130.75 | -34803 | 42.61 | 11342 | 0.0 |
| 2-65-2-W | 65-71 | 100% | 9317.90 | 266.18 | 42.42 | 11291 | -130.75 | -34803 | -42.61 | -11342 | 0.0 |
| 2-87-1-W | 87-AP | 100% | 7297.60 | 208.46 | 43.57 | 9083 | -260.94 | -54397 | 40.89 | 8524 | 0.0 |
| 2-87-2-W | 87-AP | 100% | 7297.60 | 208.46 | 43.57 | 9083 | -260.94 | -54397 | -40.89 | -8524 | 0.0 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| TOTAL REGULAR BALLAST | | | | 2548.34 | 42.87 | 109253 | -29.82 | -75994 | 0.00 | 0 | 0 |

CDI Marine

# 4 Total Ownership Costs

An initial assessment of the Total Cost of Ownership for this proposed HSSL LDS-HSC includes Development and Design cost, Acquisition or Procurement cost, and Life-Cycle Operation and Support (O&S) cost where the cost for Personnel, Maintenance, and Fuel are the drivers. Each of these items is discussed in the sections that follow, with estimates included based on a combination of ComPASS™ cost module output and applicable vendor equipment cost data.

## 4.1 Development & Design Costs

Developing and designing a large, complex Navy ship asset can cost billions of dollars and, therefore, wherever possible, this design seeks to leverage many of the same technologies being developed for more capable and more expensive ship classes, such as the new DDG 1000 class of Destroyer, so that the cost to develop this new design can be reduced, perhaps substantially. Since the design is based on an electric drive configuration, one key area where this technology transfer will be applied is in the choice of electrical components for the Integrated Power System (IPS). Specifically, the concept design calls for the use of High Temperature Superconducting Motors and Generators that are currently undergoing extensive DT&E and will ultimately provide the type of power density needed for this unique hullform design. Table 4-1 depicts the Non-Recurring lead ship design and development costs.

**Table 4-1 – Lead Ship Non-Recurring Design & Development Costs**

| COST ELEMENTS | | Per Ship | For Fleet |
|---|---|---|---|
| | **Development & Design** | | |
| | *Preliminary design cost:* | | $61,161,600 |
| | *Detail design cost:* | | $269,386,000 |
| | | | |
| | Total development cost: | | $330,547,600 |

## 4.2 Acquisition Costs

The acquisition costs cover all of the recurring cost of material for both Commercially Furnished Equipment (CFE) and Government Furnished Equipment (GFE), labor, and infrastructure support that will go into procuring this ship.

Through a process common to many manufacturing activities called "moving down the learning curve", the number of shipyard labor hours required to build a ship design decreases as a shipyard builds more ships to that design and shipyard workers become increasingly familiar with the design. This design study assumes a fleet of four LDS-HSC ships in order to satisfy the Army's Brigade Combat Team lift requirements. The costs for the lead ship and follow ships are shown in Table 4-2 along with the average acquisition cost.

Table 4-2 – Ship Acquisition Cost

| COST ELEMENTS | | Per Ship | For Fleet |
|---|---|---|---|
| | **Acquisition/Procurement** | | |
| | *Ship #1 (Lead ship)* | 1,633,540,000 | |
| | *Ship #2* | 997,057,000 | |
| | *Ship #3* | 993,180,000 | |
| | *Ship #4* | 990,936,000 | |
| | | | |
| | Average acquisition cost: | $1,153,680,000 | $4,614,720,000 |

It is worth mentioning that if this concept were to be pursued, and at that point in time, based on successful technology transfer, a lower-cost design could be procured at a greater annual rate than the currently planned design (e.g., two ships per year for the lower cost design vs. one ship per year for the currently planned design). Then the lower cost design could move down the learning curve more quickly and achieve the cost reducing benefits of the learning curve more fully than the currently planned design.

## 4.3 Life-Cycle Operation and Support (O&S) Costs

Navy as well as Military Sealift Command (MSC) ships are expensive to operate and support, and can remain in service for many years – 20 or more years for a small combatant or high-speed craft, 30 or more years for a larger surface combatant or LMSR, and up to 50 years for an aircraft carrier. Consequently, although ship procurement costs are often more visible in the budget than ship O&S costs, a ship's Life-Cycle O&S cost can contribute as much as, or even more than, its procurement cost to total long-term Navy expenditures. For this particular design, a 20-year service life with 2000 hours of operation per year was chosen. As is typical for conventionally powered ships such as this, the Life-Cycle O&S cost also includes the cost of all the fuel the ship uses over its life. The fuel cost was calculated based on actual Specific Fuel Consumption (SFC) data available from Rolls-Royce for its MT50 marine gas turbine and used as inputs to the ComPASS™ program.

Reducing a ship's Life-Cycle O&S cost can sometimes involve including design features that increase its Acquisition cost. Personnel costs are a major component of ship O&S costs, and reducing crew size can involve fitting the ship with technology for automating functions that were previously performed by ship's crew, including damage control, which is a function that traditionally has contributed to a need for a larger number of crew. If the cost of added technology is greater than the avoided expense of building extra crew-related spaces into the ship, then adding the technology will increase the ship's procurement cost. Maintenance costs are another major component of ship O&S costs, and reducing maintenance costs might require building certain parts of the ship with more durable but more expensive materials, or increasing the size (and thus construction cost) of certain spaces on the ship so as to provide room for easier access during maintenance. Both of these cost trade-offs were considered during the design synthesis of this vessel, which resulted in a crew size of 24 persons, of which 15% are

officers and 25% are non-commissioned officers (licensed personnel). Space arrangements, in particular machinery arrangements, were developed to facilitate both the initial build (producibility) of the ship and its different levels of required maintenance.

**Table 4-3 – Ship Life-Cycle O&S Costs**

| | | Per Ship | For Fleet |
|---|---|---|---|
| COST ELEMENTS | **Life-Cycle Operation & Support (O&S)** | | |
| | *Fuel cost per year:* | $37,973,500 | $151,894,000 |
| | *Other non-fuel consumable cost per year:* | $13,881,600 | $55,526,400 |
| | *Recurring investment per year:* | $7,082,775 | $28,331,100 |
| | *Indirect cost (administrative) per year:* | $1,221,753 | $4,887,010 |
| | **Personnel** | | |
| | *Crew labor cost per year:* | $780,498 | $3,121,990 |
| | **Maintenance** | | |
| | *Engine maintenance cost per year:* | $11,566,700 | $46,266,800 |
| | *Hull maintenance cost per year:* | $6,276,910 | $25,107,640 |
| | Total maintenance cost per year: | $17,843,610 | $71,374,440 |
| | Total maintenance hours per year: | 194116 | 776463 |
| | | | |
| | Total operational cost per year: | $78,783,750 | $315,135,000 |
| | | | |
| | Average total annual cost: | $140,600,000 | $562,400,000 |
| | Average total hourly cost: | $70,300 | |
| | **Total Life-Cycle Cost for a 20 Year Service Life:** | **$2,812,000,000** | **$11,248,000,000** |

# 5 Summary and Conclusions

This report describes a concept ship designed by CDI Marine Systems Development Division (CDIM-SDD). The design was developed for the U.S. Navy's Office of Naval Research (ONR) as part of their High-Speed Sea Lift (HSSL) program solicited under ONR Broad Agency Announcement (BAA) #05-007. The design was started initially by CDIM-SDD while under subcontract to SAIC in Annapolis, Maryland, who ,in turn, were under contract to ONR in response to the BAA's Subtopic B program of work that focused on improving "Computational Approaches and Hydrodynamic Tools" for future ship designs. As such, the concept was conceived to not only satisfy the mission goals desired by ONR, but also to create a broad scope of design information, particularly concerning the hydrodynamics of the below-water shape of the hulls, that would challenge the predictive capability of the tools being developed for the BAA Subtopic B.

The subject vessel is a concept ship that can easily transform itself to operate either as a Catamaran, a SWATH, or as an SES. The catamaran was chosen because of its good high-speed efficiency and seakeeping performance, low risk, low cost, good payload arrangeability and compatibility with the SES concept. The SWATH was chosen because of its inherently good seakeeping, and the SES because of its ability to afford shallow draft with cushion end seals deployed for gaining access to Austere Ports, and to combine with the SWATH to enhance seakeeping at low speed for transferring cargo to and from a sea base in heavy seas. This latter combination is achieved by ballasting the vessel to transform from a Cat mode to a SWATH mode, in combination with deploying the cushion end seals and a cushion divider, and supplying air to the cushion as in an SES with active control of cushion air flow and, hence, control of cushion pressure fore and aft of the divider that provides significant dynamic control of ship pitch and heave in a seaway.

All these modes of operation were tested by CDIM-SDD with a scale model of the concept ship at the David Taylor Model Basin at Carderock Maryland, in December of 2006. Testing of the HSSL model was very successful. It demonstrated the ability to achieve the desirable full-scale draft goal, and the ship's resistance as a Catamaran was very repeatable and provided a good database for verifying ship powering predictions. In the SWATH mode, the motions of the model were excellent – 1.1 feet of RMS heave in sea state 5 and 3.2 feet in sea state 6. These motions may be low enough for RO/RO operation without the need for motion control. SES motion control was encouraging, but could have benefited significantly with more time devoted to tuning the control system.

In response to the performance and design goals specified by ONR, a ship was evolved through various iterations and trade-off studies that examined steel and aluminum structure, various types of power plants and power distribution systems, propulsor systems, and several different configurations for below-water hull geometry in an attempt to reduce ship drag and powering requirements.

The principal conclusions drawn from the study are summarized as follows:

1. A balanced ship can be designed and built that will meet all of the hard and soft mission, performance and design goals listed by ONR.

2. The structure and top sides of the vessel need to be constructed of aluminum alloy. This would be the largest aluminum ship structure built to date and would therefore come with increased risk. It has an overall length of 580 ft compared to the current largest stir-welded aluminum ship structure built for the Japanese TSL SES at 460 ft.

3. The ship requires over 400,000 shp for propulsion and for providing air for the SES cushion. Although this requirement is large, there are aero derivative gas turbine engines being developed by industry that can be arranged to power the ship within an Integrated Power System (IPS) architecture.

4. The axial-flow waterjets required to fit in the limited space on the transom of the ship will require development as well as the generators and motors for the IPS.

5. The accurate prediction of resistance of the complex shape of the below-water surfaces of the hulls was initially a significant challenge. However, SAIC exercised their potential flow code Das Boot and, with optimization performed using their "Shape" code, drag was reduced and a surrogate drag predictor was developed for the CDI design tool ComPASS™, which produced results that closely matched the results of model tests.

6. The resulting complex shape of the demihulls would, however, make it more challenging to dry dock such a vessel.

7. The vessel is equipped with a system to control pitch and heave motion in a seaway to minimize the risk of transferring cargo at the sea base. However, tests conducted with a model of the concept suggested that motions in the SWATH mode in sea state 5 were sufficiently low to possibly render the motion control system unnecessary.

8. Finding enough room on board for adequate sea water ballast in the SWATH mode became a serious challenge. If, subsequently, the SES motion control system is deemed unnecessary, then far less ballast would be necessary.

9. The overall project produced a number of significant challenges, but promising solutions were developed. These solutions are not all low risk, so a moderate amount of development would be necessary to bring this ship to fruition.

# 6 References


1. "Modern Ships & Craft" Chapter VI, "The Surface Effect Ship" Special Edition of the Naval Engineer's Journal, February 1985 by Edward A. Butler.

2. "Model Tests of a Low-Draft, High-Speed Connector (LDS-HSC) Vessel for The ONR High-Speed Sea Lift (HSSL) Program", by CDIM-SDD, March 2007.

3. "Modification to COMPASS™ Wave Drag Routine for Catamarans", by CDIM-SDD, July 2006.

4. "The SWATH Concept: Designing Superior Operability into a Surface Displacement Ship", DTNSRDC Report No. 4570, G. Robert Lamb, December 1975.

5. "Resistance Experiments on a Systematic Series of High-Speed Displacement Catamaran Forms" by Molland, Wellicome and Couser; RINA, 1995.

6. "ONR HSSL Program Phase II Final Report: Computational Approach and Hydrodynamic Technologies for High-Speed Sealift to Austere Ports", by SAIC-Led Team, April 2007.

# APPENDIX A1 FLOODABLE LENGTH CURVE

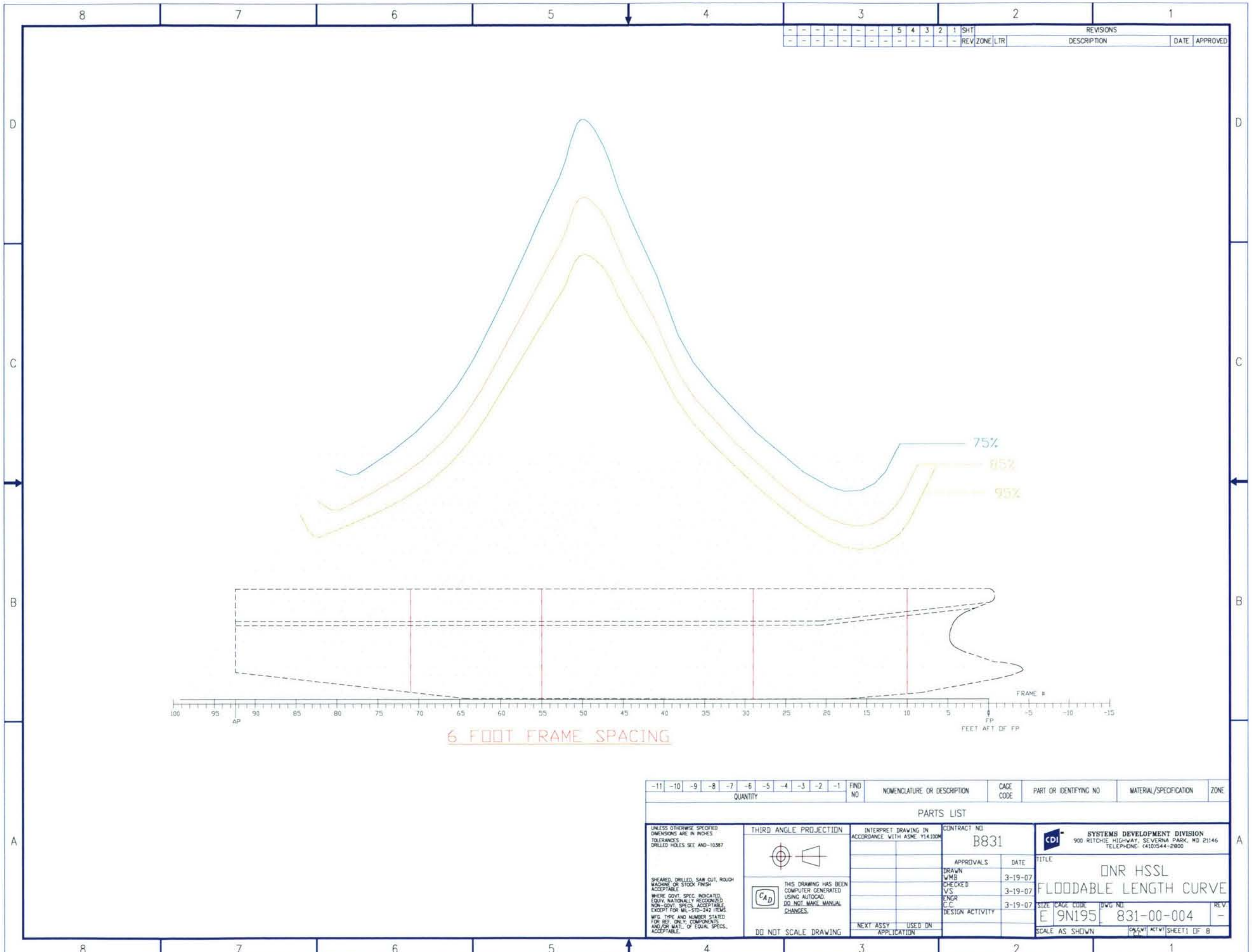


**Figure A-1 Floodable Length Curve**

# APPENDIX A2 GENERAL ARRANGEMENTS

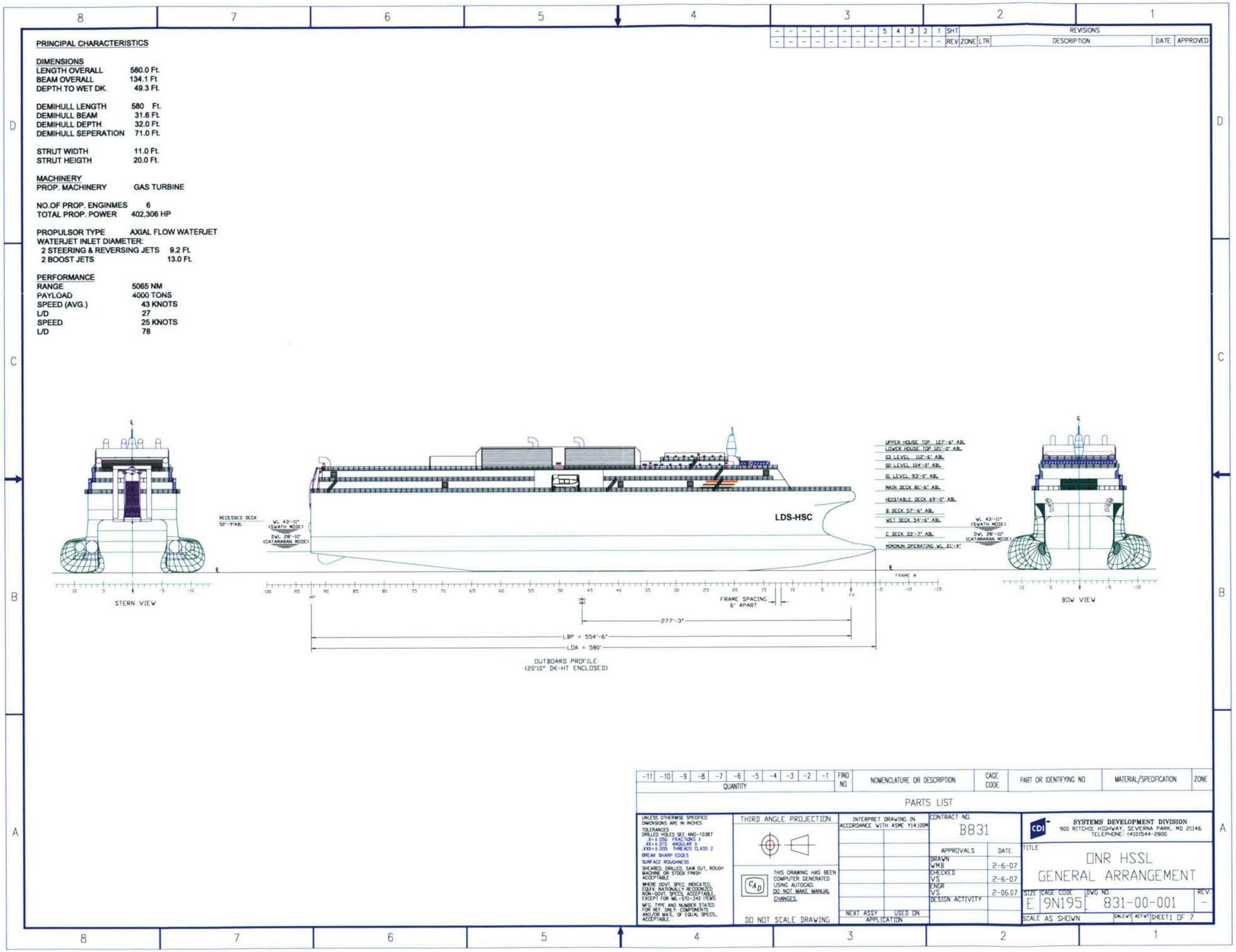


**Figure A-2 Outboard Profile and Bow & Stern Views**

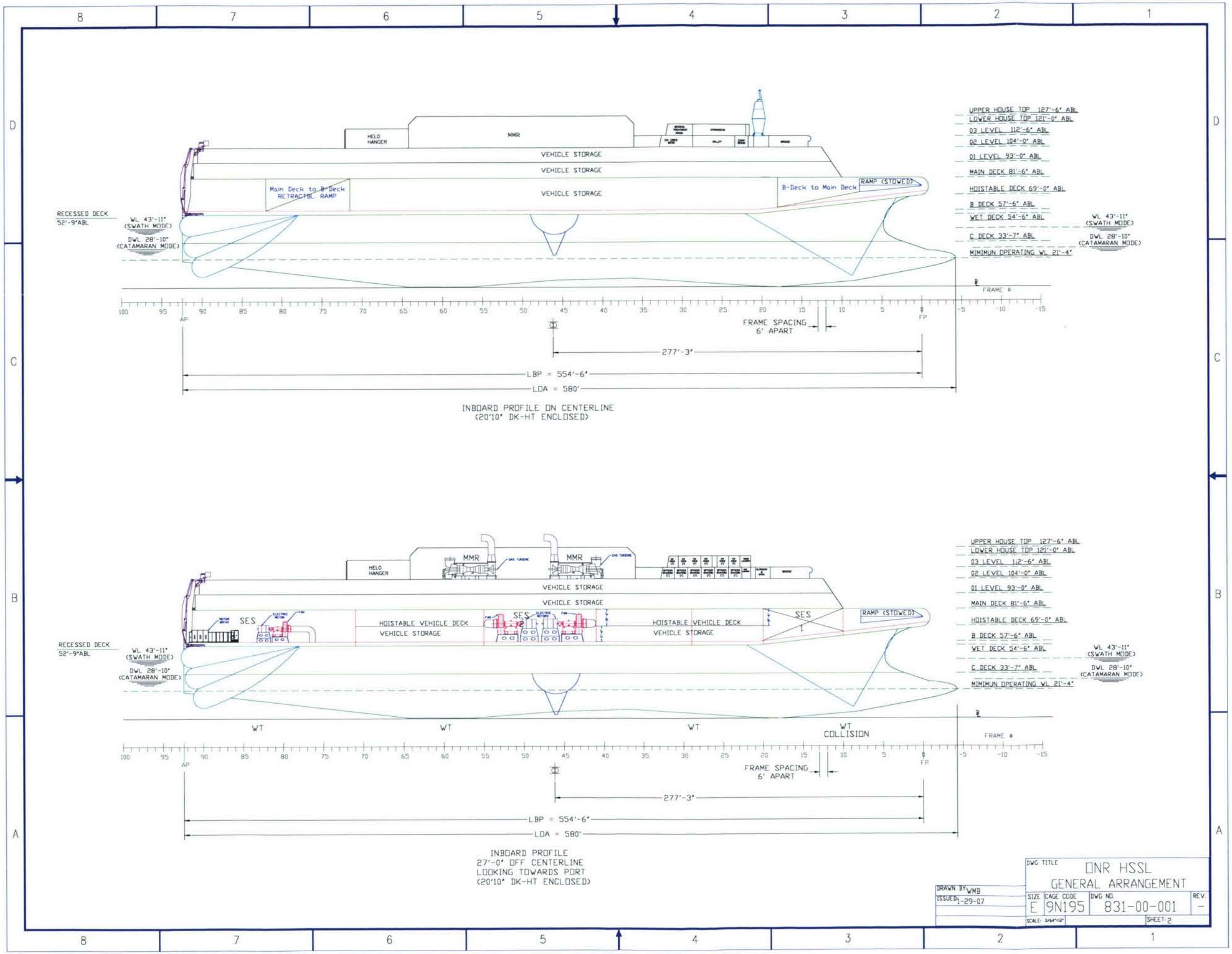


**Figure A-3 Inboard Profiles**

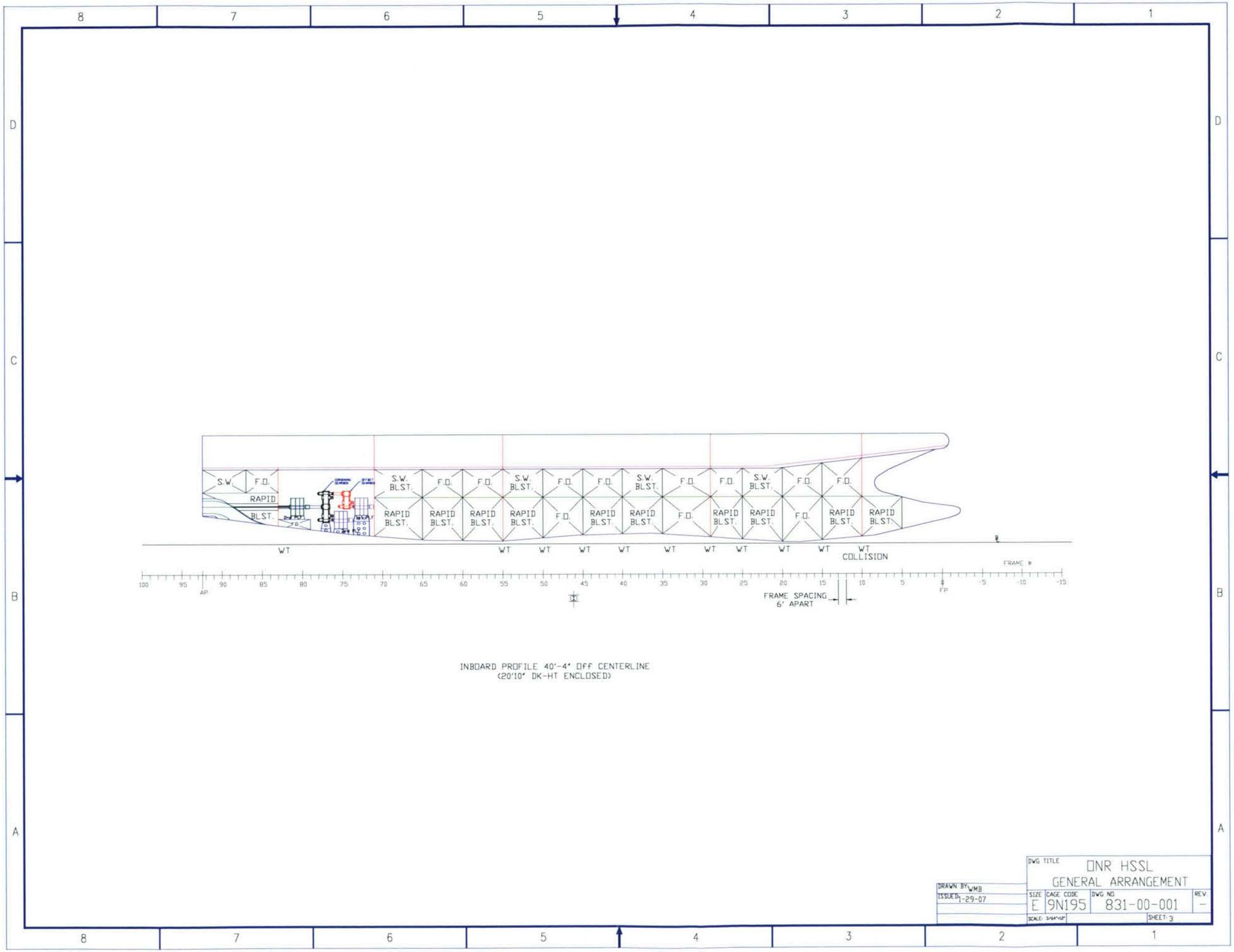


**Figure A-4 Inboard Profile showing Tankage Arrangement**

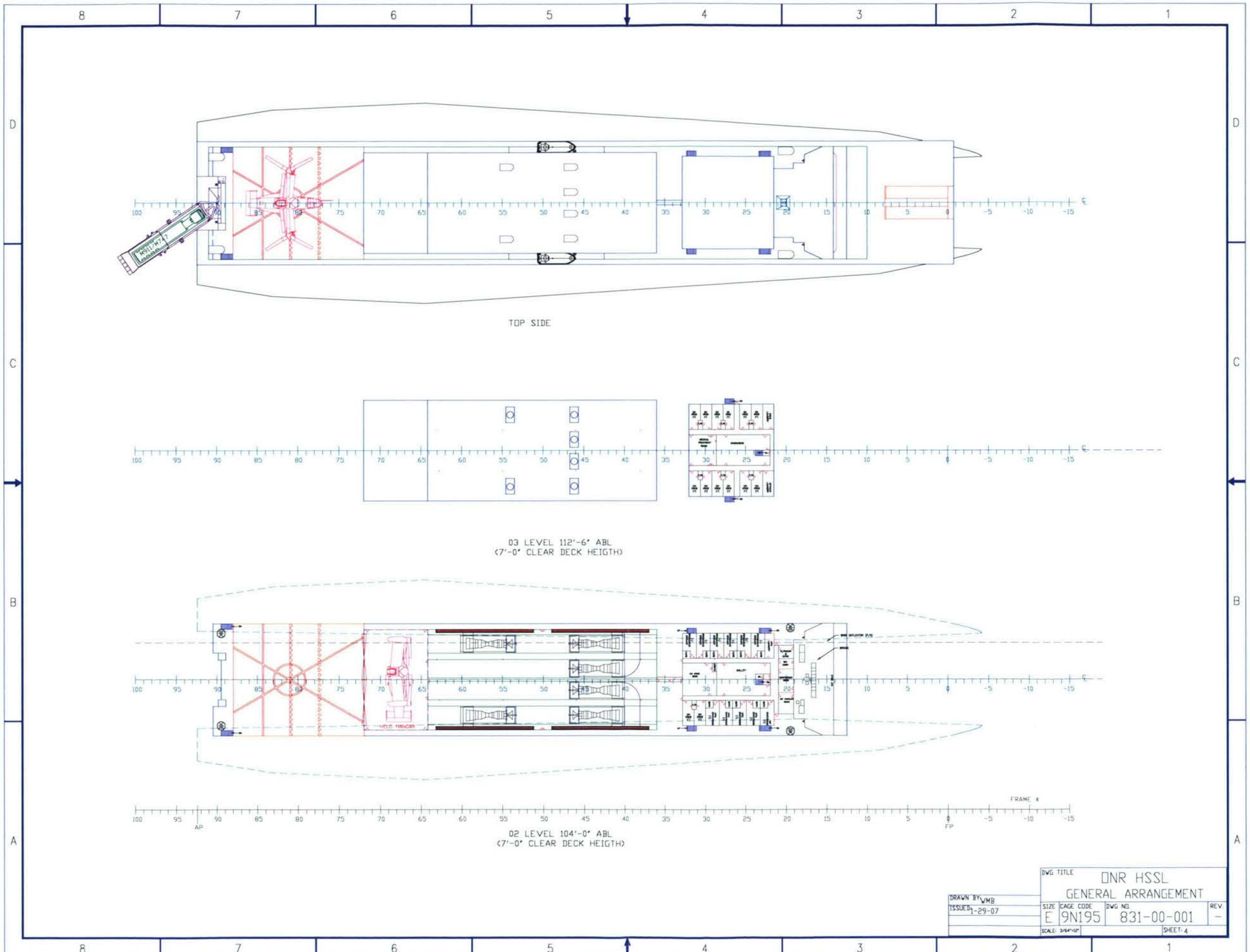


**Figure A-5 Topside, 03 Level, and 02 Level Deck Plans**

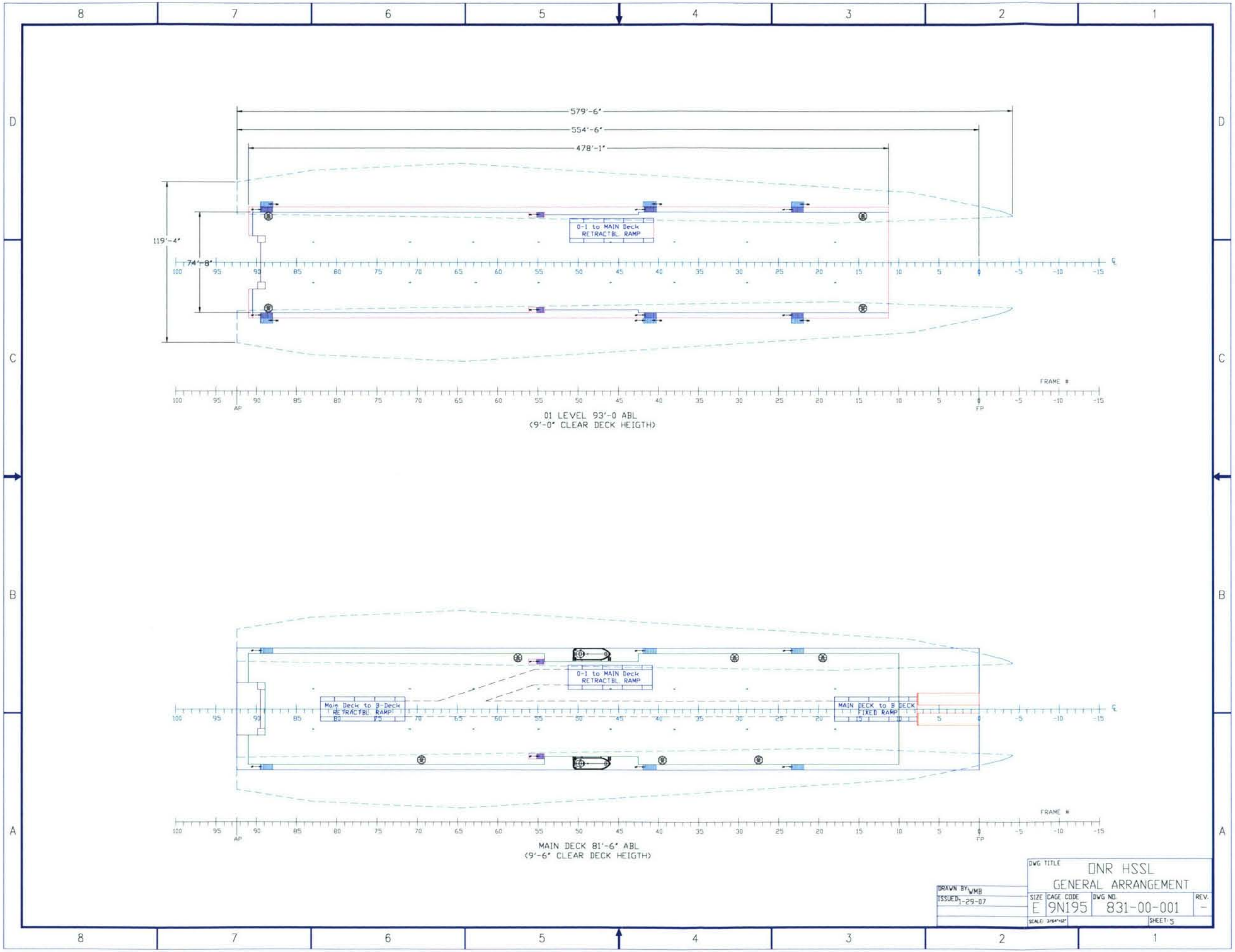


**Figure A-6 01 Level and 02 Level Deck Plans**

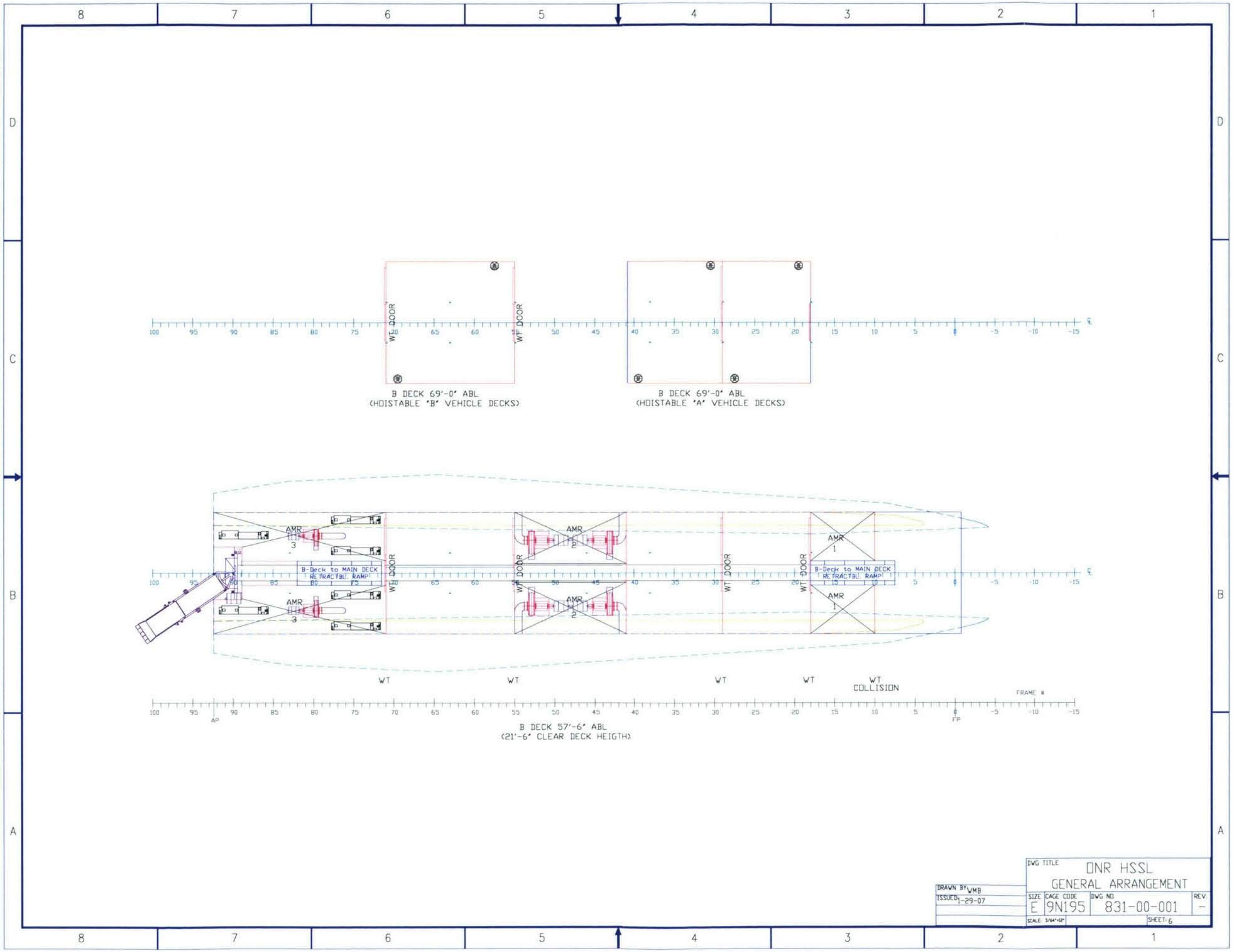


**Figure A-7 B Deck and Hoistable Deck Plans**

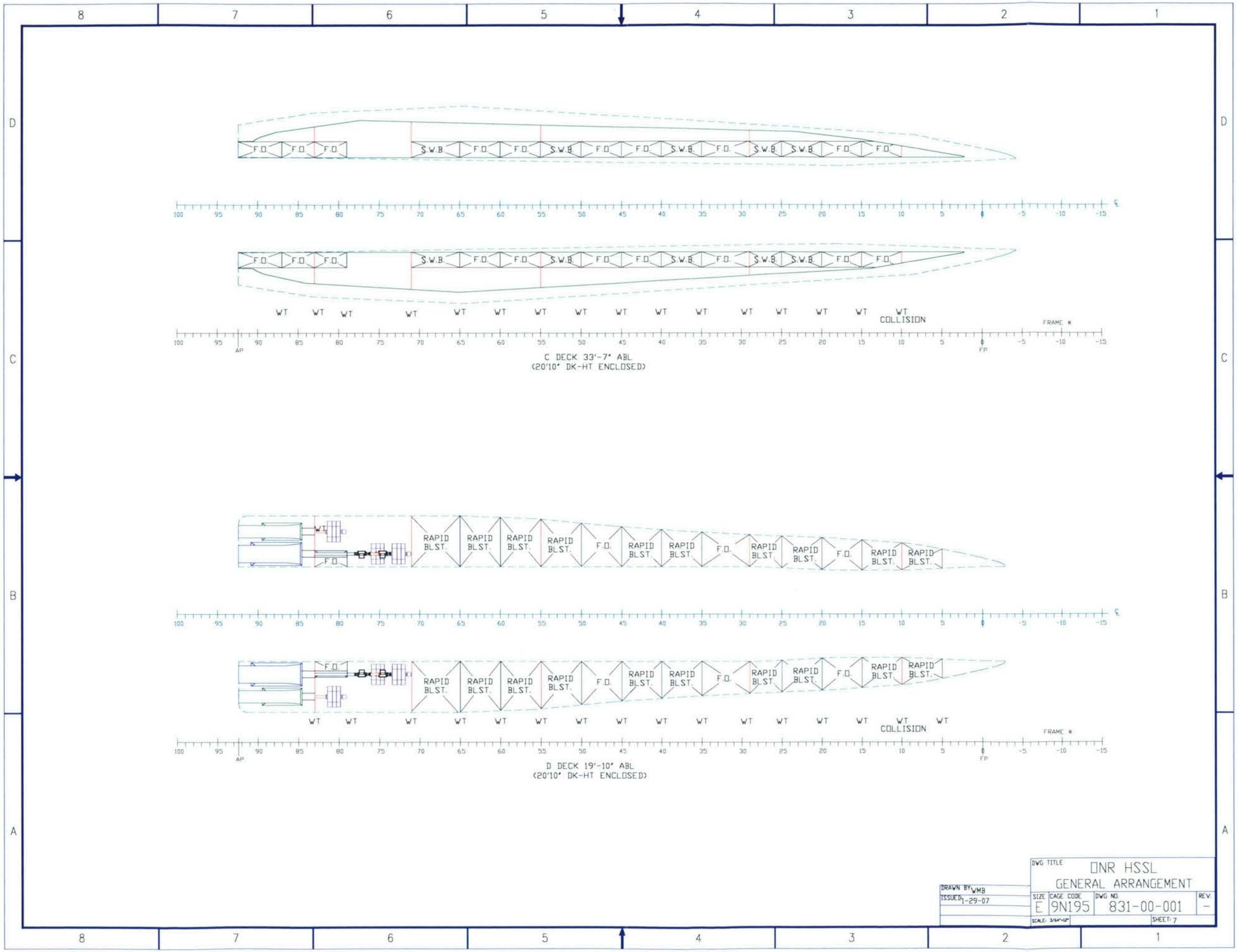


**Figure A-8 C Deck and D Deck Plans**

# APPENDIX A3 MACHINERY ARRANGEMENTS

| - | - | - | - | - | - | - | - | 5 | 4 | 3 | 2 | 1 | SHT | REVISIONS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - | - | - | - | - | - | REV | ZONE | LTR | DESCRIPTION | DATE | APPROVED |

| -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | FIND NO | NOMENCLATURE OR DESCRIPTION | CAGE CODE | PART OR IDENTIFYING NO | MATERIAL/SPECIFICATION | ZONE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QUANTITY | | | | | | | | | | | | | | | | |

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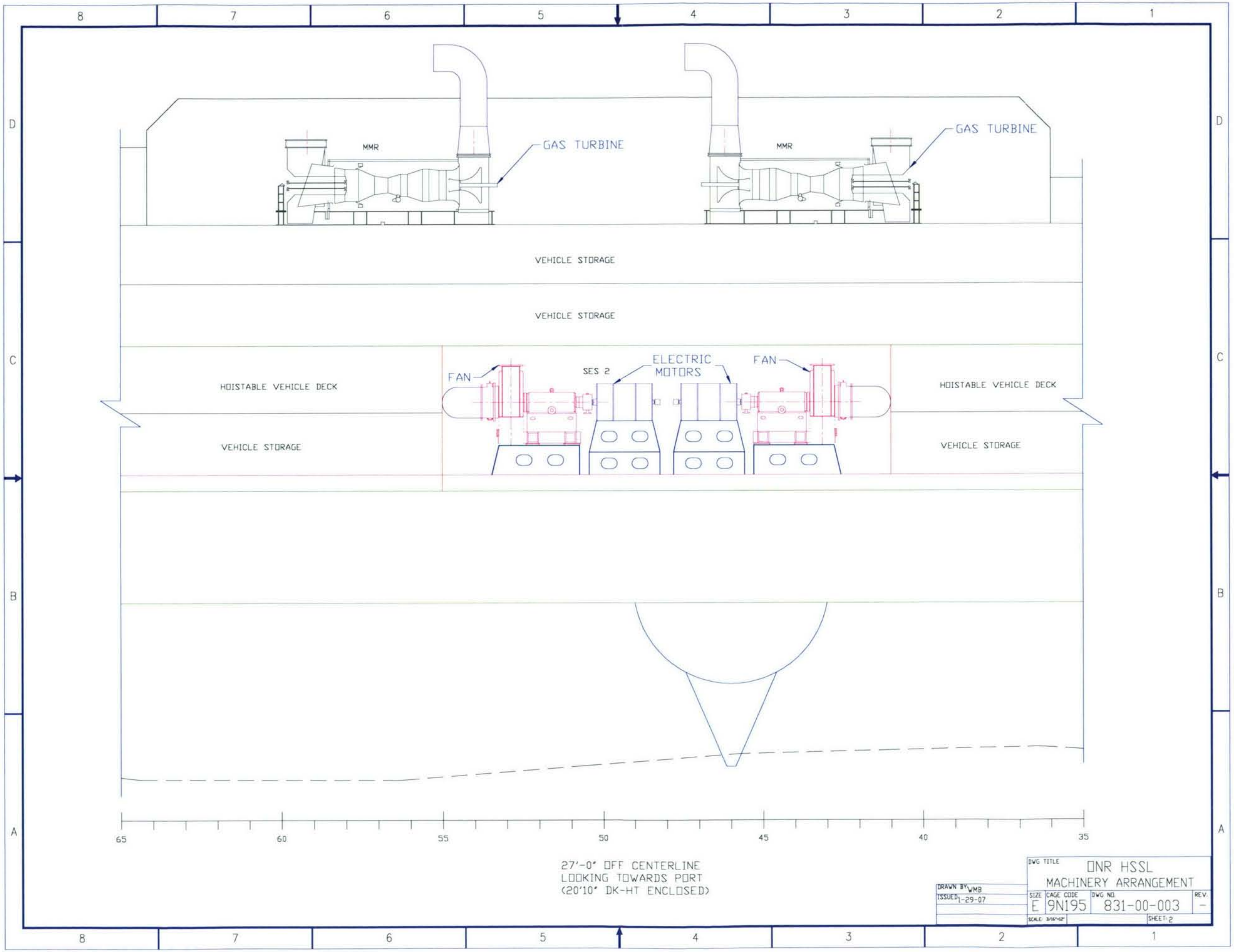



**Figure A-9 Inboard Profile of Main and Amidships Auxiliary Machinery Rooms**

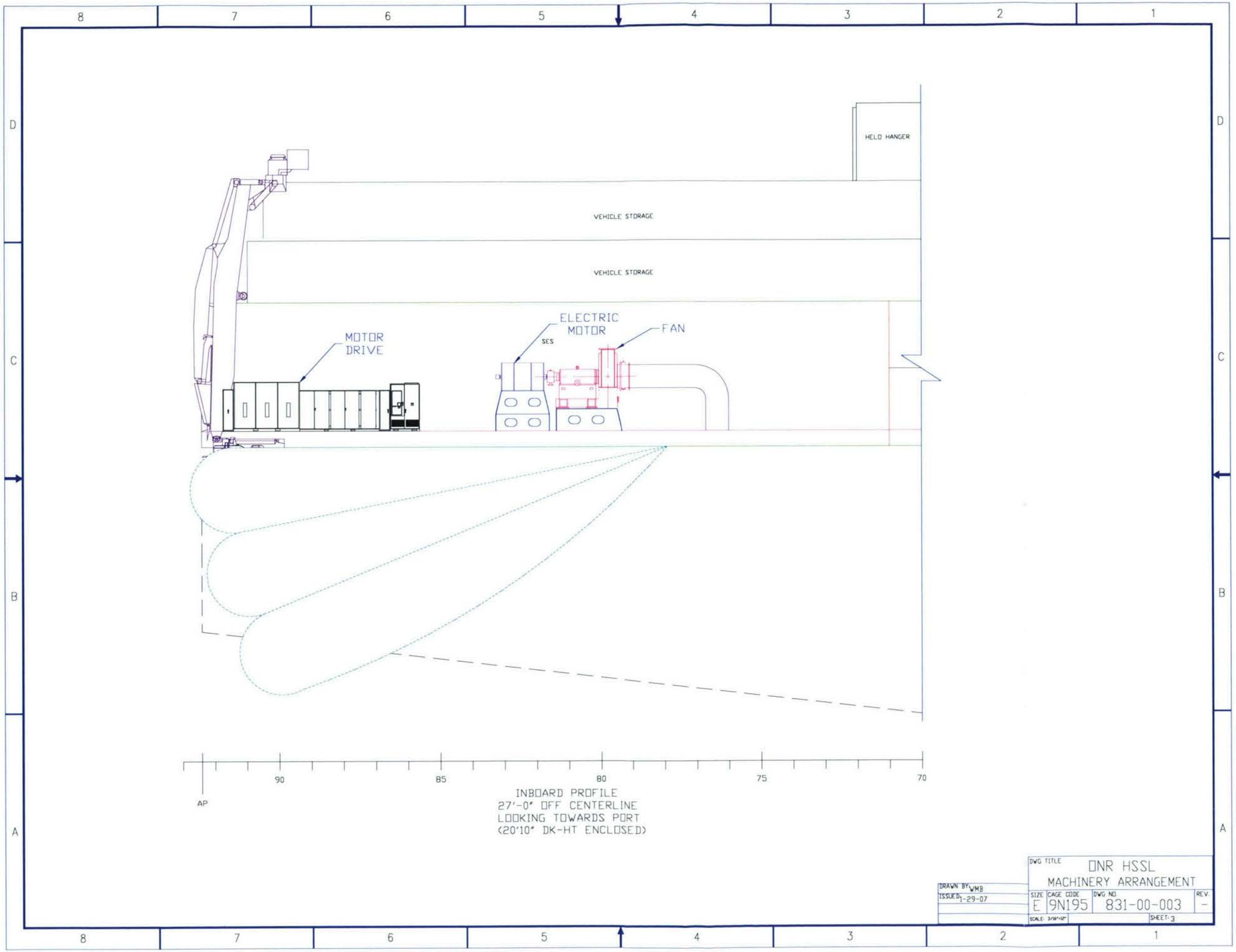



**Figure A-10 Inboard Profile of Aft Auxiliary Machinery Room**

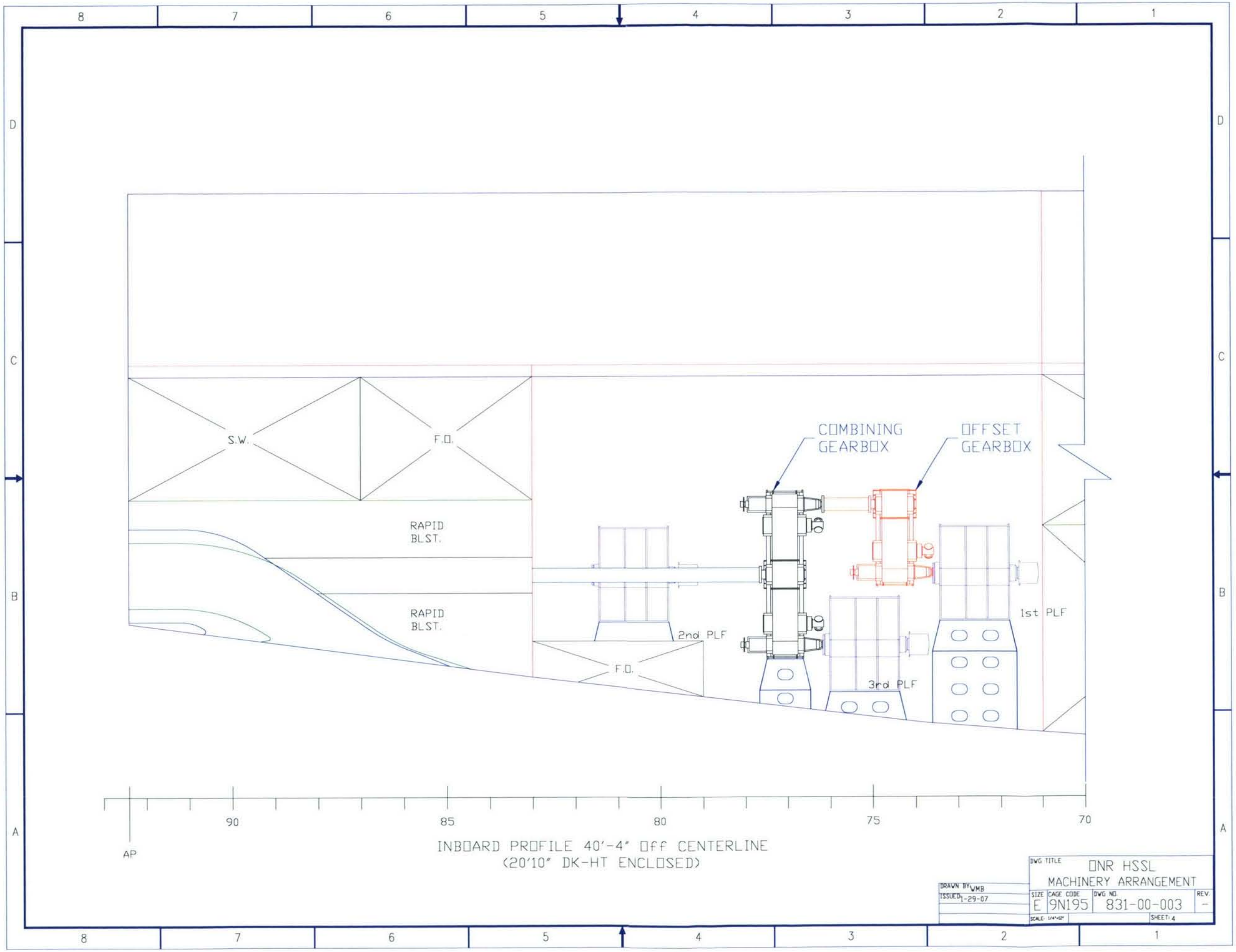



Figure A-11 Inboard Profile of Propulsion Machinery Room

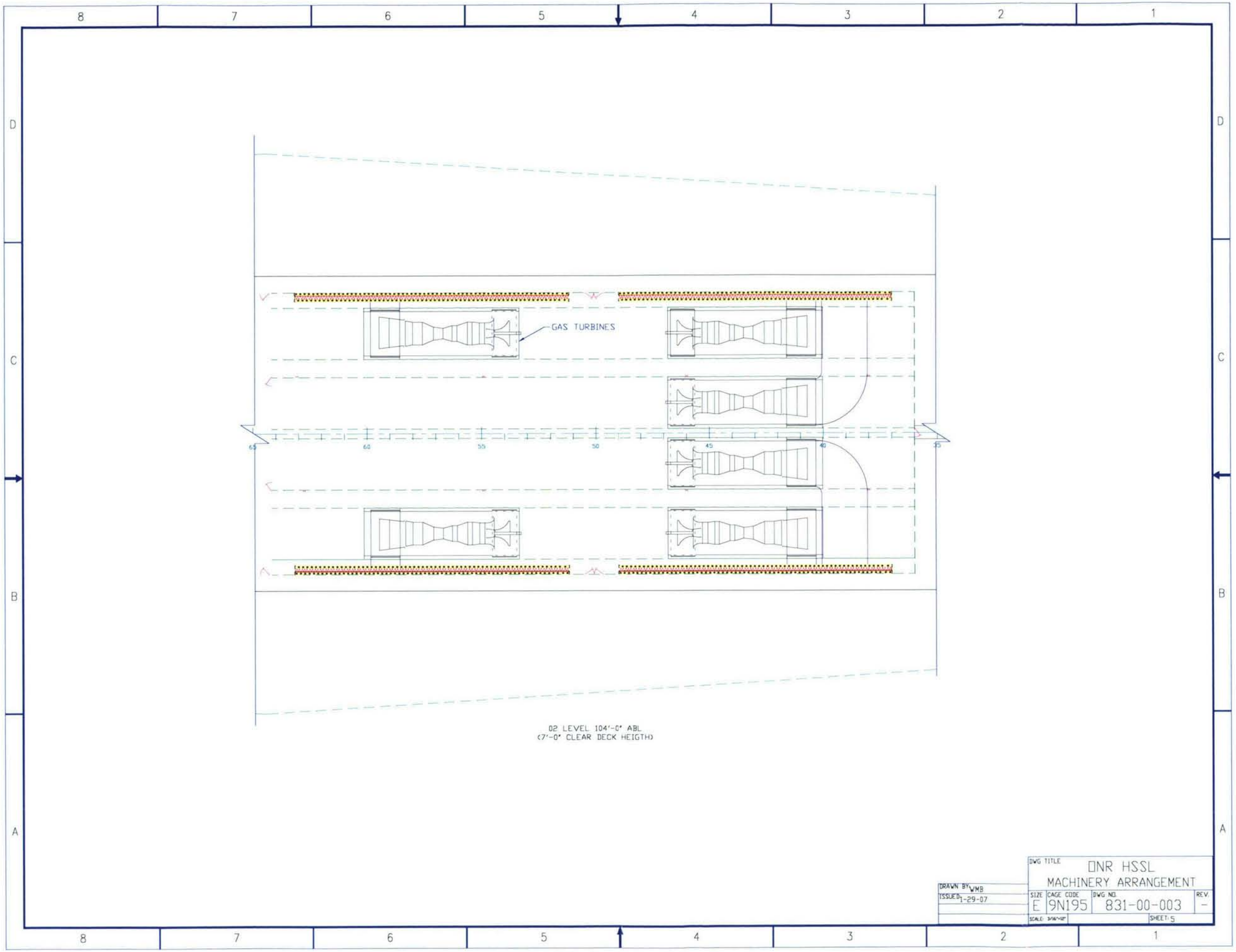



**Figure A-12 Plan View of Gas Turbine Generator (GTG) Machinery Room**

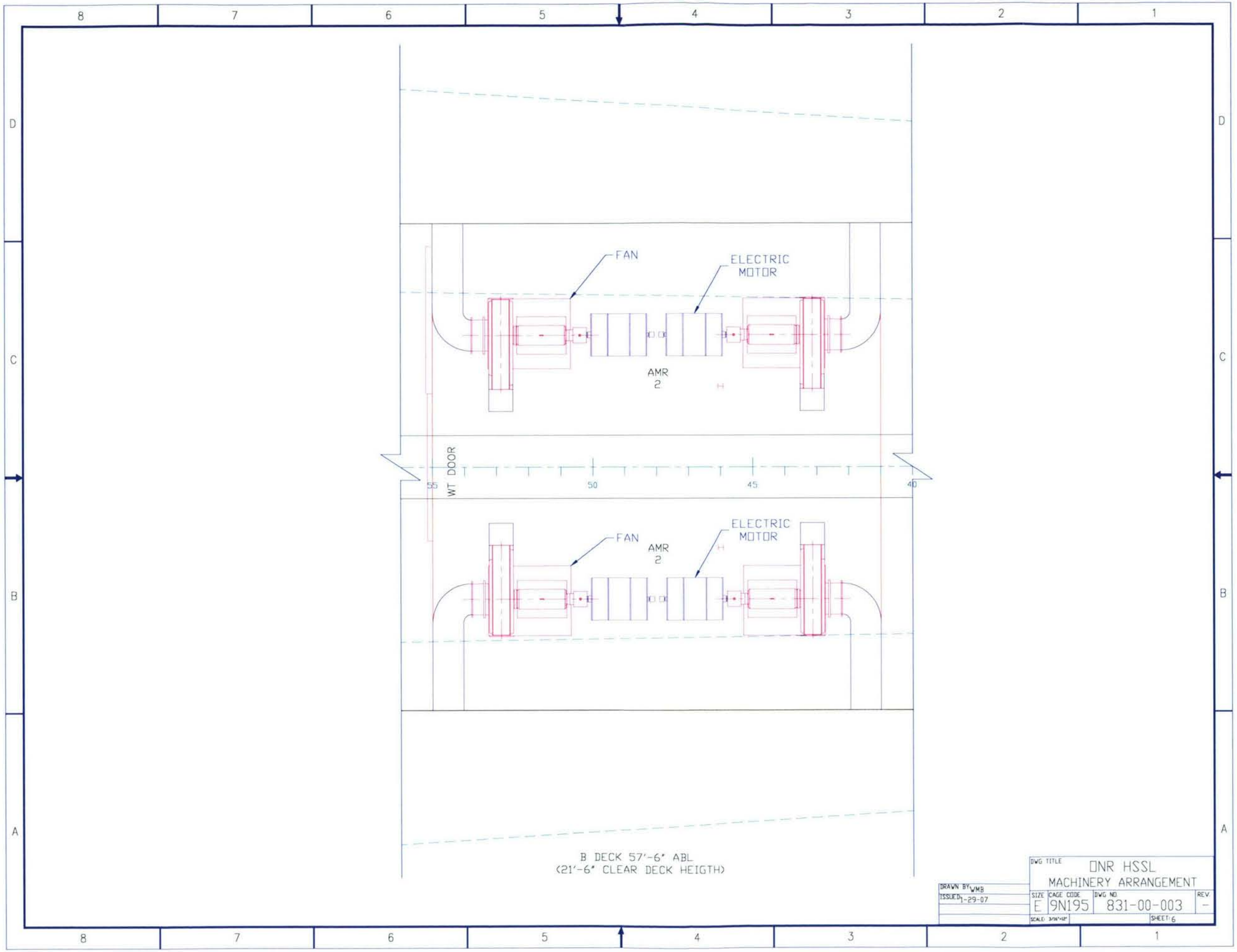



Figure A-13 Plan View of Amidships Auxiliary Machinery Room (AMR #2)

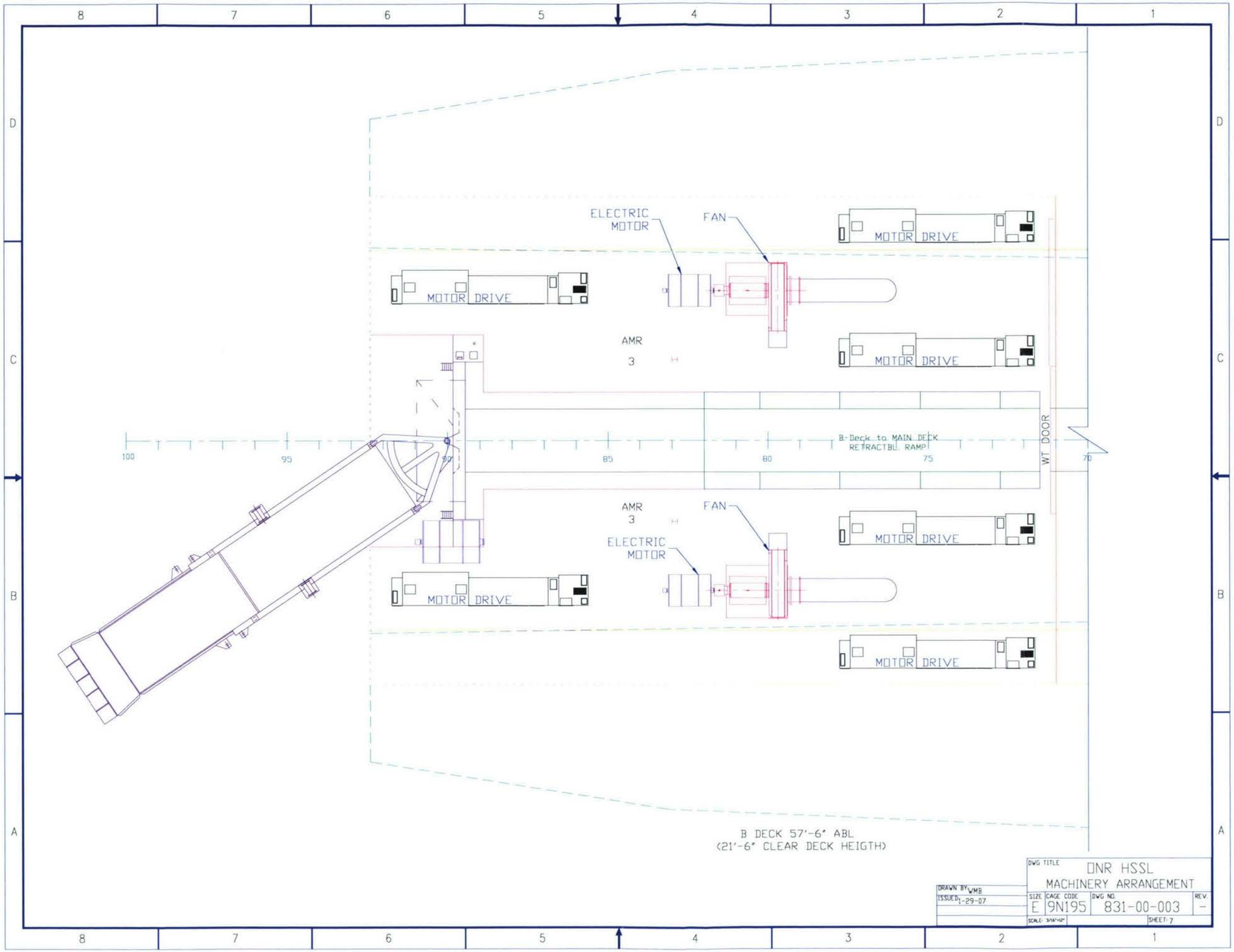



Figure A-14 Plan View of Aft Auxiliary Machinery Room (AMR #3)

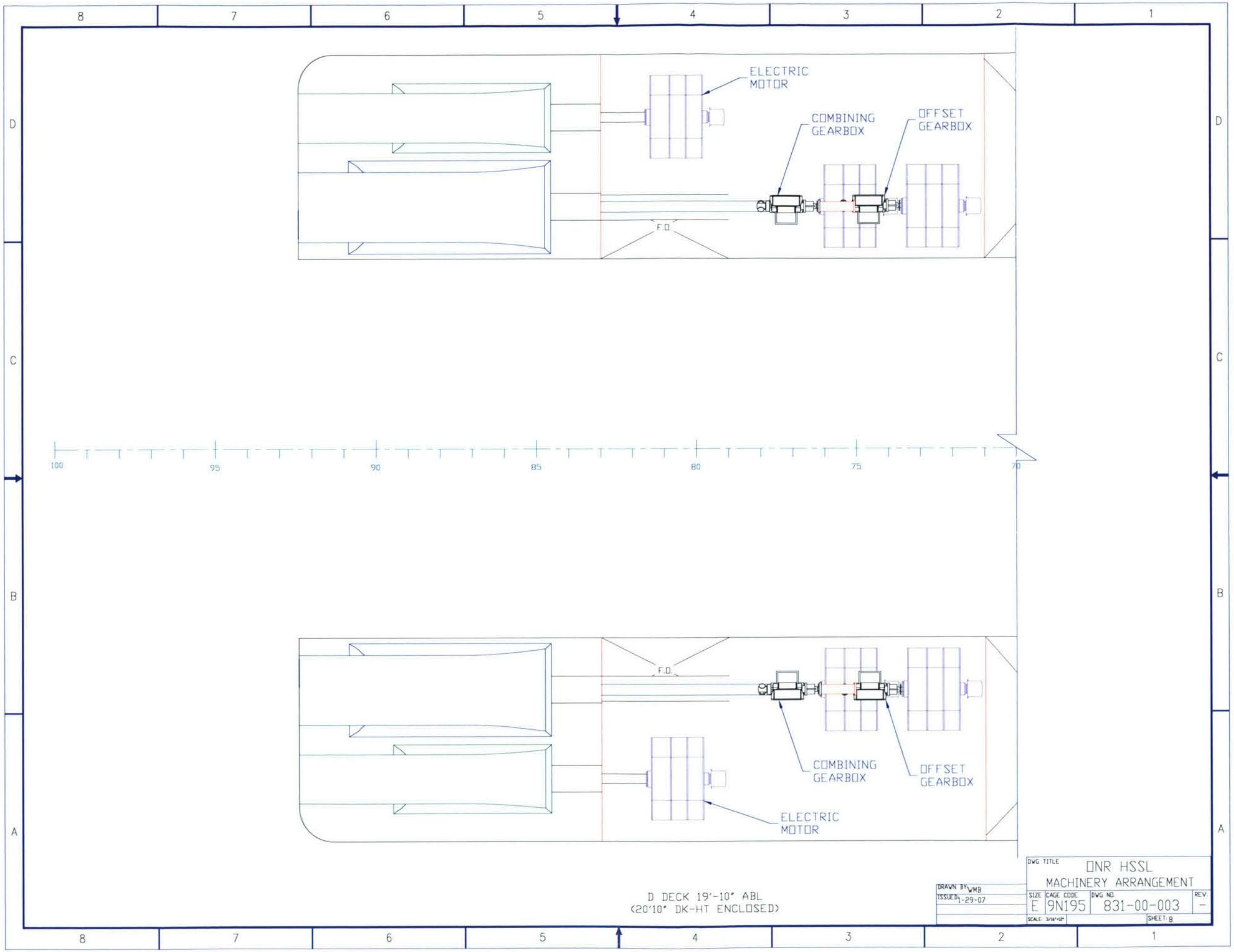



**Figure A-15 Plan View of Propulsion Machinery Rooms**

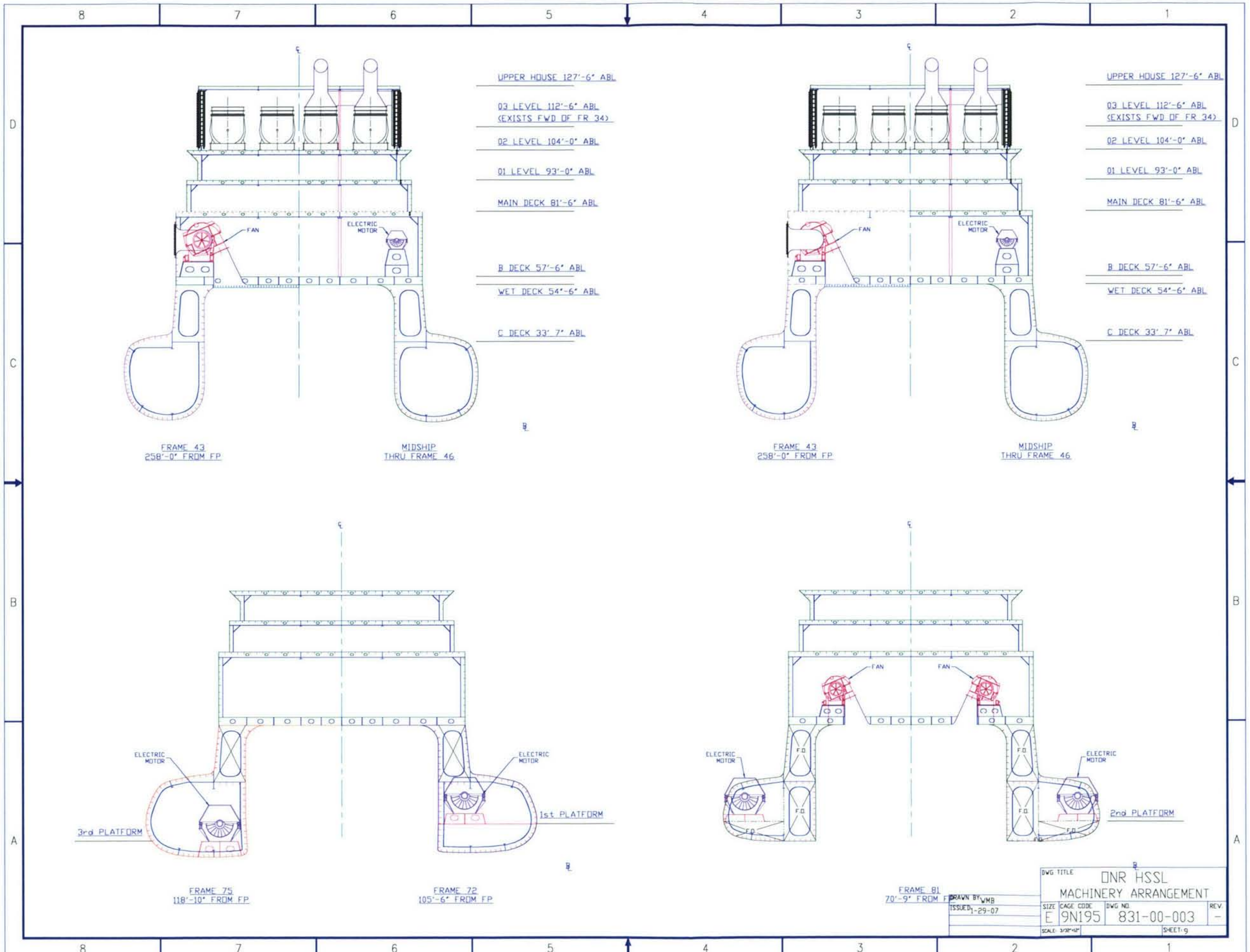
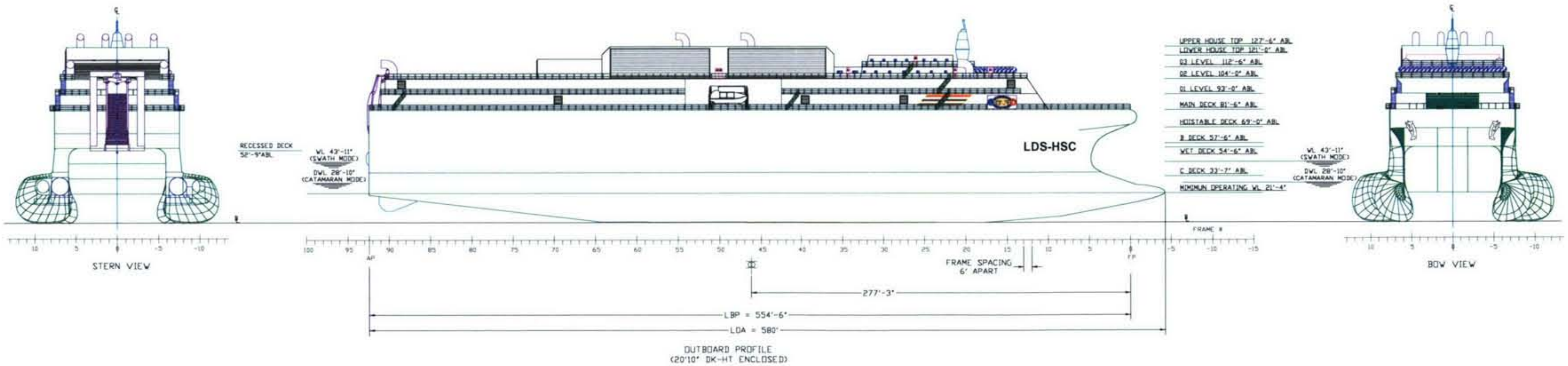



**Figure A-16 Section Views of Machinery Spaces**

# APPENDIX A4 PAYLOAD ARRANGEMENTS

VEHICLE LOCATIONS

| TYPE | DESCRIPTION | Qty. Needed | LOCATIONS QTY "B" Deck | Main Deck | 01 Level | Hoistable A | Hoistable B |
|---|---|---|---|---|---|---|---|
| M1135 | NBC RECONNAISSANCE VEHICLE | 3 | | | 3 | | |
| M1127 | RECONNAISANCE VEHICLE | 30 | | 25 | 5 | | |
| M198 | 155mm HOWITZER | 30 | | 30 | | | |
| M1129 | MOTAR CARRIER | 19 | | | 19 | | |
| M1126 | INFANTRY CARRIER VEHICLE | 70 | 40 | | 30 | | |
| M1128 | MOBILE GUN SYSTEM | 15 | 15 | | | | |
| M1134 | ANTI TANK GUIDED MISSILE | 5 | | | 5 | | |
| M1135 | NBC RECONNAISSANCE VEHICLE | 3 | | | 3 | | |
| M1131 | FIRE SUPPORT VEHICLE | 3 | | | 3 | | |
| M1132 | ENGINEER SUPPORT VEHICLE WITHOUT PLOW | 5 | | 5 | | | |
| M1132/PLOW | JUST THE PLOW | 5 | 5 | | | | |
| M1133 | MEDICAL EVACUATION VEHICLE | 5 | | | 5 | | |
| M998 | CARGO TROOP CARRIER | 67 | | | | 18 | 49 |
| M1044 | ARMAMENT CARRIER/WINCH | 48 | | 17 | 27 | 4 | |
| M149A2 | TRAILER TANK WATER | 25 | | | | 25 | |
| M102 | HIGH MOBILITY 1/4 TON CARGO TRAILER | 25 | | | | 25 | |
| M101 | HIGH MOBILITY 3/4 TON CARGO TRAILER | 25 | | 25 | | | |
| M1083 | DISTRIBUTION COMPANY | 5 | | 5 | | | |
| M978 | DISTRIBUTION COMPANY | 5 | | | 5 | | |
| M911/M747 | DISTRIBUTION COMPANY | 5 | 5 | | | | |

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|---|---|
| DRAWN WMB | 4-11-07 |
| CHECKED VS | 4-11-07 |
| ENGR VS | 4-11-07 |
| DESIGN ACTIVITY | |

SYSTEMS DEVELOPMENT DIVISION
900 RITCHIE HIGHWAY, SEVERNA PARK, MD 21146
TELEPHONE: (410)544-2800

TITLE
ONR HSSL
PAYLOAD LOCATIONS

SIZE E | CAGE CODE 9N195 | DWG NO. 831-00-005 | REV. -
SCALE AS SHOWN | CALC WT | ACT WT | SHEET 1 OF 3

**Figure A-17 Payload Arrangements**

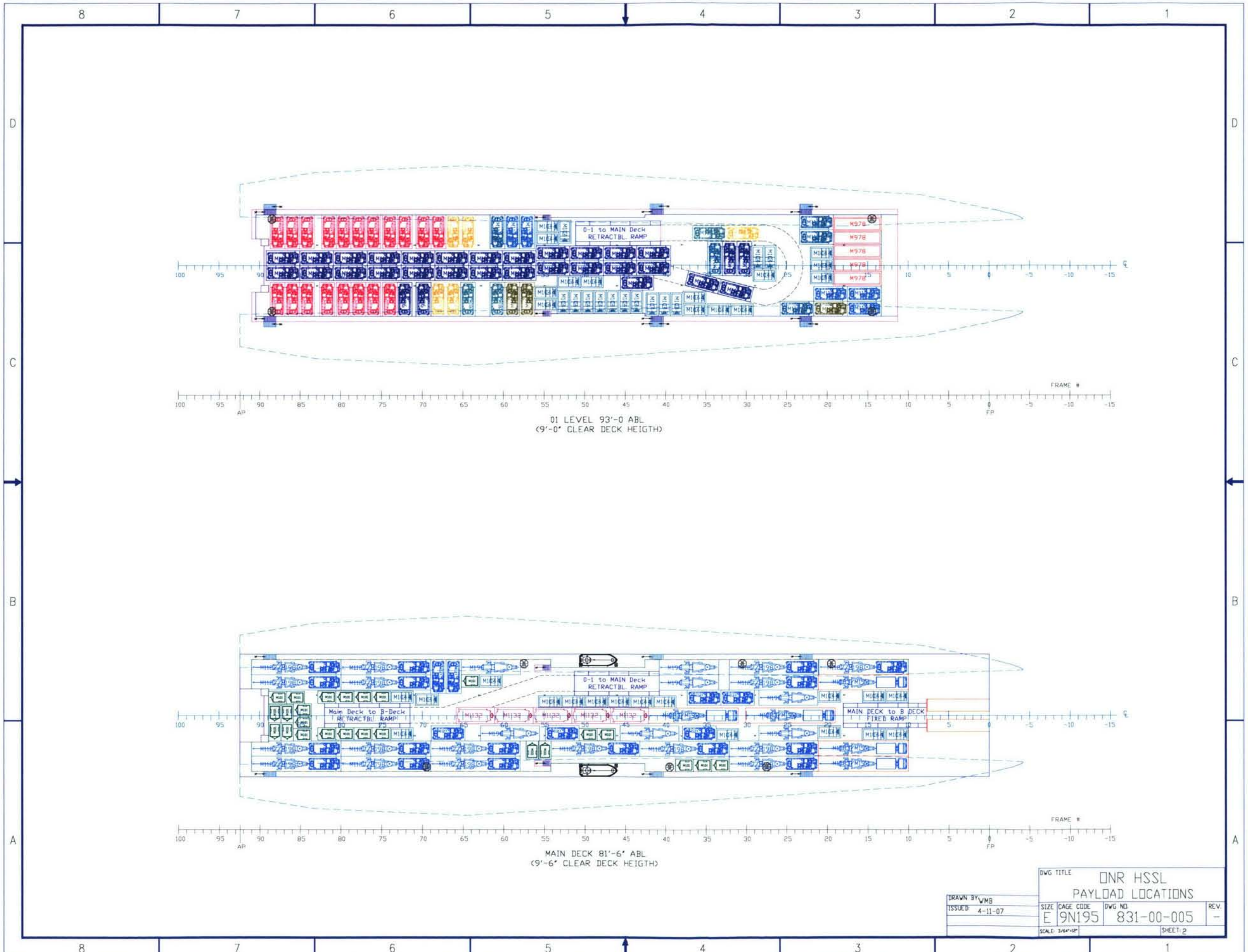


**Figure A-18 01 Level and Main Deck Payload Arrangements**

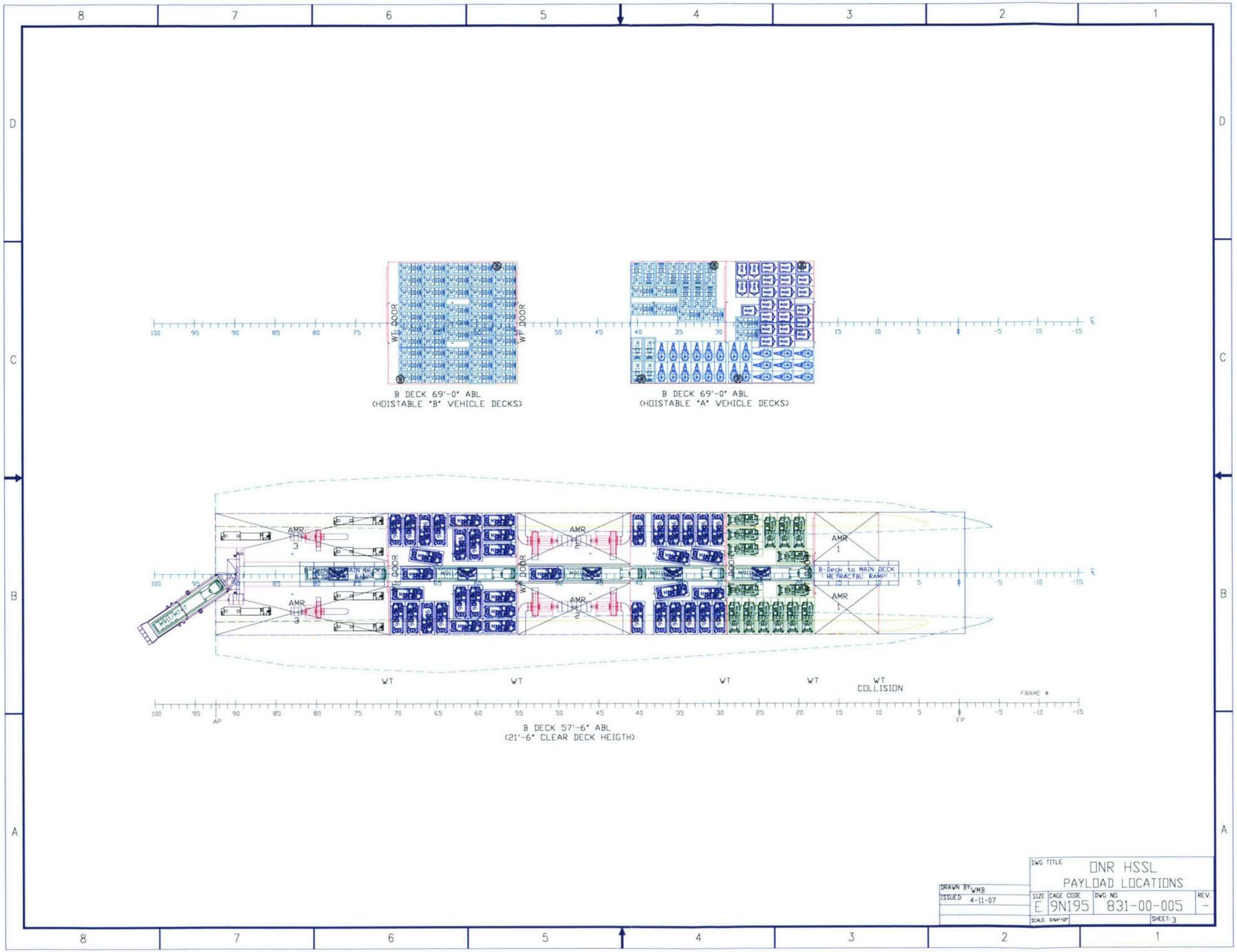


Figure A-19 B Deck and Hoistable Deck Payload Arrangements

# APPENDIX A5 STRUCTURAL SCANTLINGS

| - | - | - | - | - | - | - | - | 5 | 4 | 3 | 2 | 1 | SHT | REVISIONS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - | - | - | - | - | - | REV | ZONE | LTR | DESCRIPTION | DATE | APPROVED |

NOTES:

1. ALL MATERIAL AL-5456 ALUMINUM ALLOY OR EQUIVALENT.

| -11 | -10 | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | FIND NO | NOMENCLATURE OR DESCRIPTION | CAGE CODE | PART OR IDENTIFYING NO | MATERIAL/SPECIFICATION | ZONE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QUANTITY | | | | | | | | | | | | | | | | |

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
DRILLED HOLES SEE AND-10387

SHEARED, DRILLED, SAW CUT, ROUGH MACHINE OR STOCK FINISH ACCEPTABLE
WHERE GOVT. SPEC. INDICATED, EQUIV. NATIONALLY RECOGNIZED NON-GOVT. SPECS. ACCEPTABLE, EXCEPT FOR MIL-STD-242 ITEMS.
MFG. TYPE AND NUMBER STATED FOR REF. ONLY; COMPONENTS AND/OR MATL. OF EQUAL SPECS., ACCEPTABLE.

THIRD ANGLE PROJECTION

CAD

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DO NOT SCALE DRAWING

INTERPRET DRAWING IN ACCORDANCE WITH ASME Y14.100M

| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

CONTRACT NO.
B831

| APPROVALS | DATE |
|---|---|
| DRAWN WMB | 4-16-07 |
| CHECKED VS | 4-16-07 |
| ENGR M.G. | 4-16-07 |
| DESIGN ACTIVITY | |

CDI
SYSTEMS DEVELOPMENT DIVISION
900 RITCHIE HIGHWAY, SEVERNA PARK, MD 21146
TELEPHONE: (410)544-2800

TITLE
ONR HSSL
STRUCTURAL

| SIZE | CAGE CODE | DWG NO | REV |
|---|---|---|---|
| E | 9N195 | 831-00-002 | - |

SCALE AS SHOWN | CALC WT | ACT WT | SHEET1 OF 5

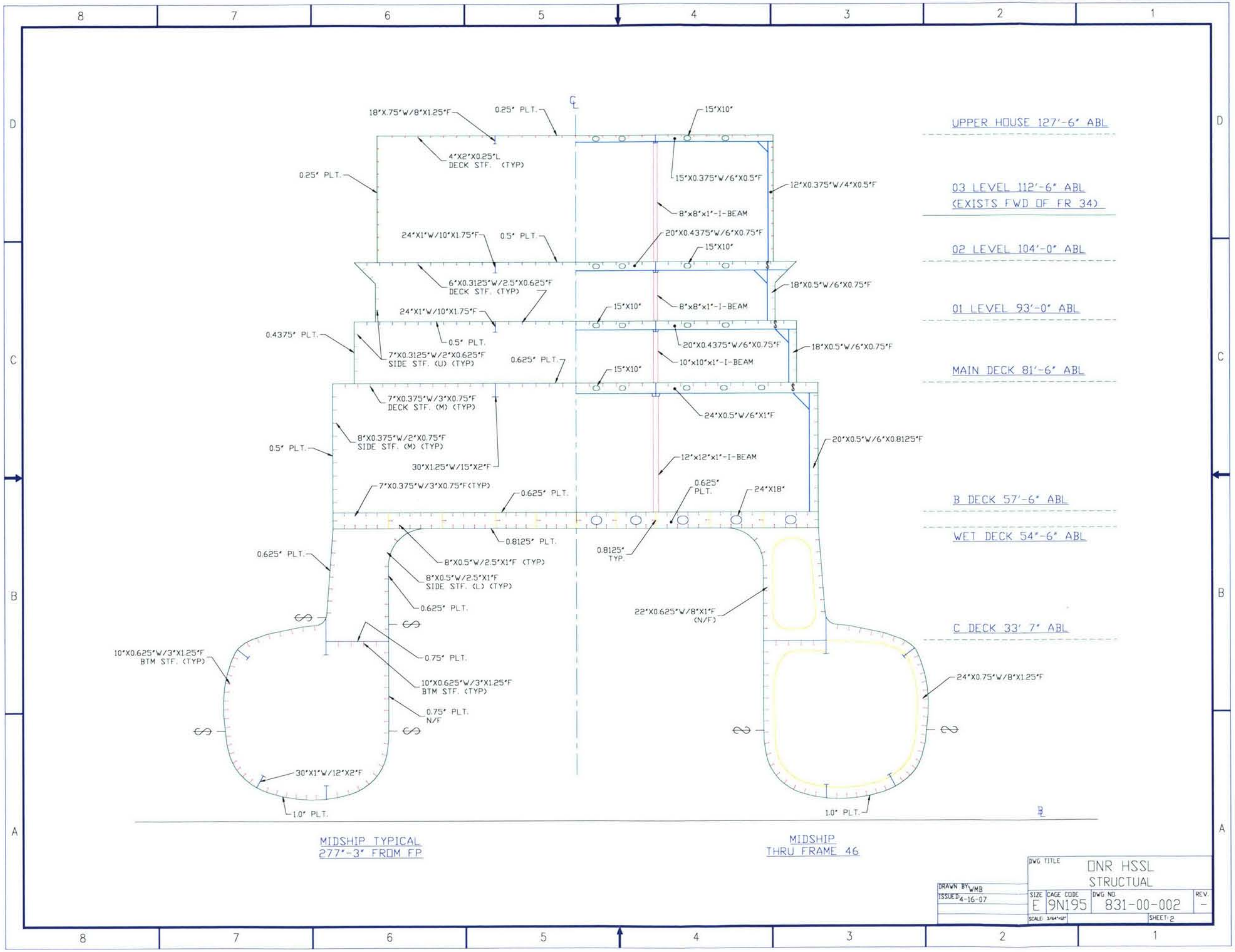


**Figure A-20 Midship Structural Scantlings**

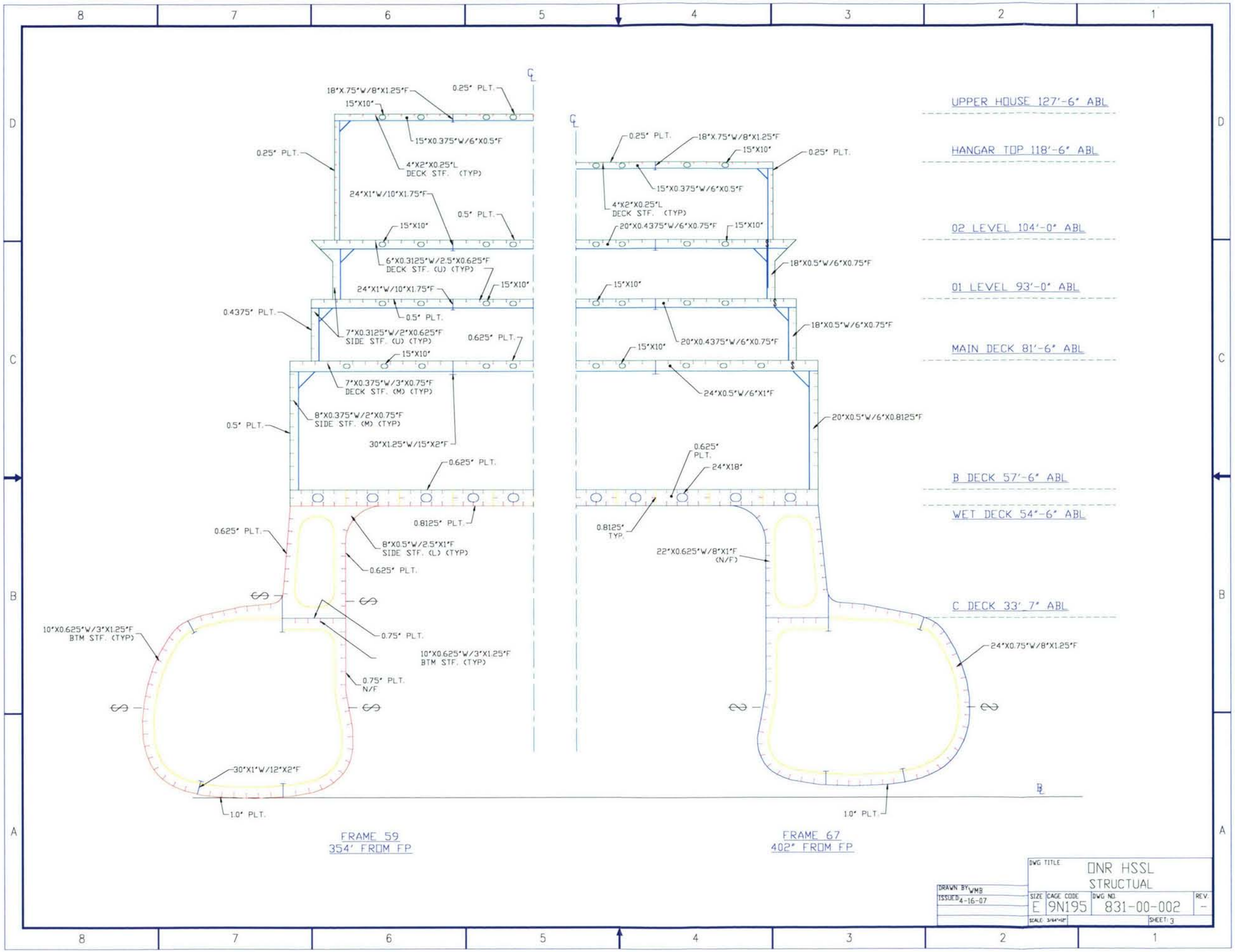


**Figure A-21 Frames 59 & 67 Structural Scantlings**

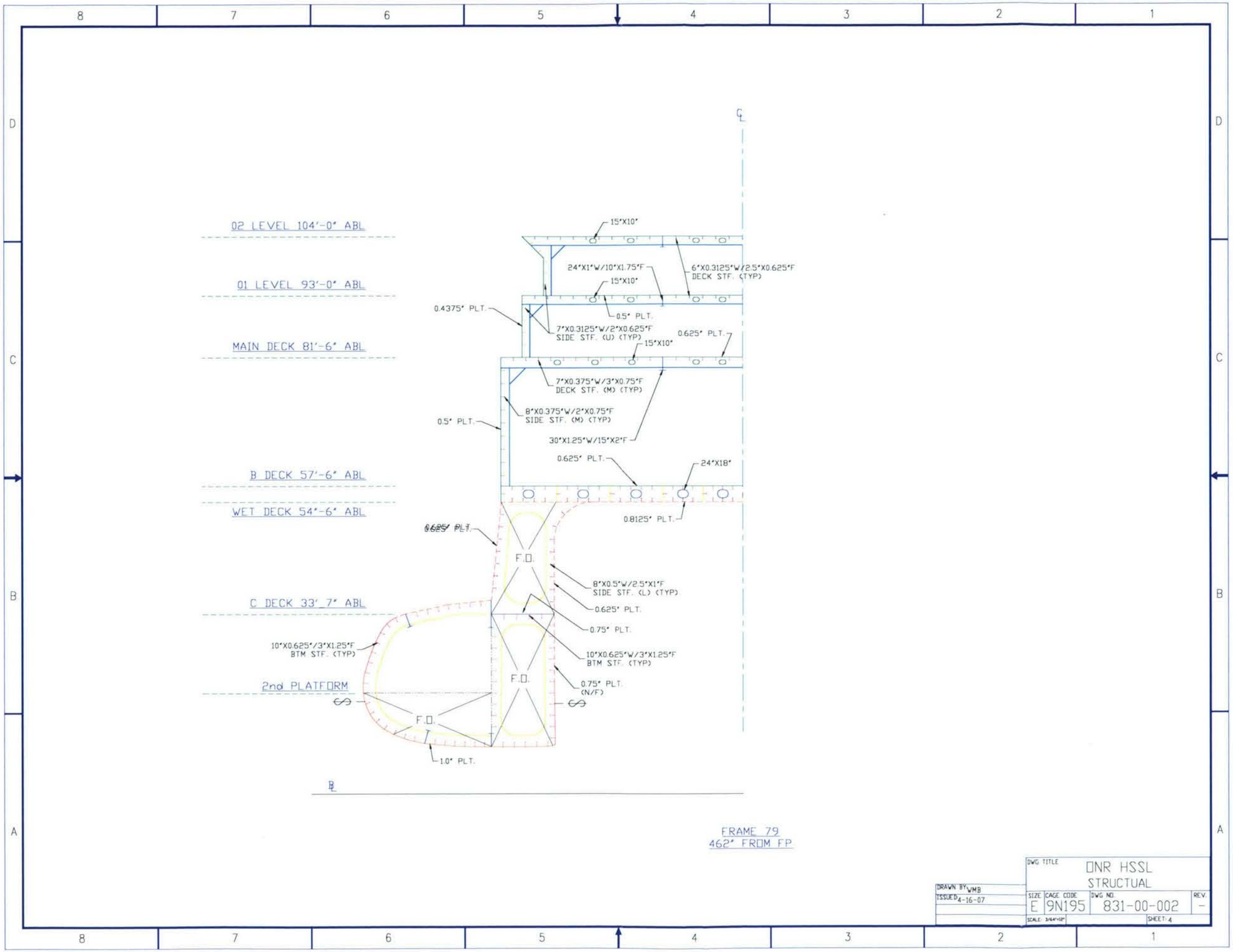


**Figure A-22 Frame 79 Structural Scantlings**

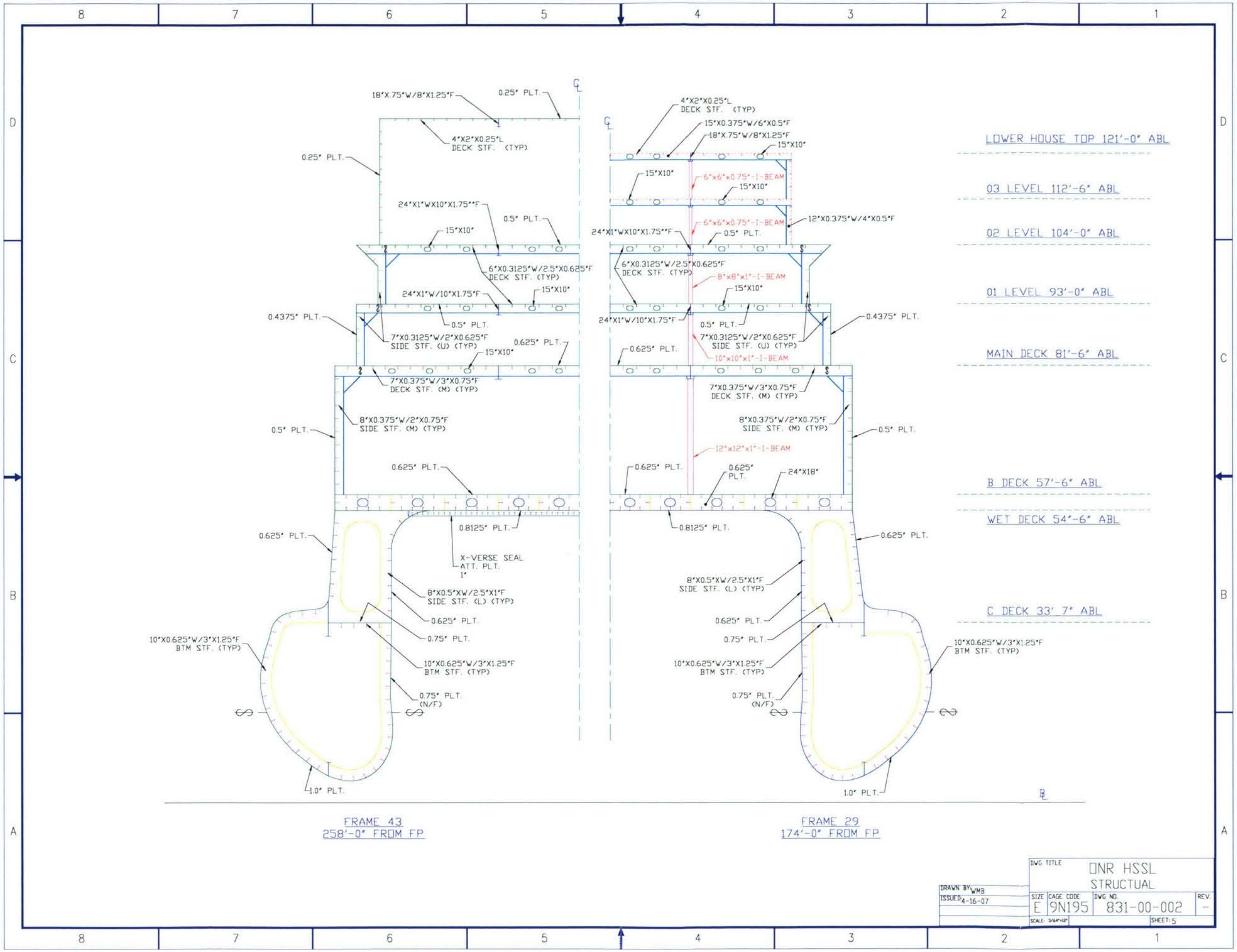


**Figure A-23 Frames 29 & 43 Structural Scantlings**

# APPENDIX B – TABLE OF HYDROSTATICS

| MEAN KEEL DRAFT (ft) | TOTAL DISPLACEMENT SW (LT) | FW (LT) | TRANV. KM (ft) | LONG. KM (ft) | TPI | MCT 1" MT/in | LCB (ft Aft FP) | LCF (ft Aft FP) |
|---|---|---|---|---|---|---|---|---|
| 0.72 | 21.34 | 20.80 | 7342.00 | 23738.56 | 5.06 | 146.55 | 328.98 | 313.76 |
| 1.45 | 87.10 | 84.92 | 3449.20 | 14948.31 | 10.00 | 349.86 | 310.01 | 298.26 |
| 2.17 | 194.19 | 189.34 | 2238.13 | 10766.92 | 14.61 | 533.02 | 301.31 | 291.32 |
| 2.90 | 340.54 | 332.03 | 1656.15 | 8463.35 | 19.05 | 703.58 | 296.01 | 287.09 |
| 3.62 | 525.09 | 511.97 | 1316.36 | 7010.62 | 23.42 | 865.52 | 292.31 | 284.16 |
| 4.35 | 747.63 | 728.94 | 1095.56 | 6009.59 | 27.81 | 1021.32 | 289.53 | 281.90 |
| 5.07 | 1008.99 | 983.76 | 943.30 | 5273.14 | 32.38 | 1172.29 | 287.28 | 279.85 |
| 5.79 | 1312.66 | 1279.84 | 844.26 | 4710.42 | 37.86 | 1323.24 | 285.27 | 276.94 |
| 6.52 | 1663.33 | 1621.74 | 749.31 | 4221.01 | 42.59 | 1461.64 | 283.32 | 275.51 |
| 7.24 | 2050.46 | 1999.20 | 664.23 | 3820.45 | 46.41 | 1588.43 | 281.81 | 275.29 |
| 7.97 | 2468.59 | 2406.88 | 594.08 | 3498.12 | 49.75 | 1707.22 | 280.73 | 275.58 |
| 8.69 | 2914.18 | 2841.33 | 536.42 | 3234.80 | 52.74 | 1818.84 | 279.98 | 276.18 |
| 9.42 | 3384.39 | 3299.78 | 488.57 | 3015.28 | 55.42 | 1923.11 | 279.51 | 276.95 |
| 10.14 | 3876.82 | 3779.90 | 448.50 | 2831.51 | 57.86 | 2021.80 | 279.24 | 277.93 |
| 10.86 | 4389.57 | 4279.83 | 414.57 | 2676.87 | 60.10 | 2116.52 | 279.16 | 279.12 |
| 11.59 | 4921.02 | 4798.00 | 385.53 | 2545.59 | 62.17 | 2208.35 | 279.23 | 280.51 |
| 12.31 | 5469.77 | 5333.03 | 360.42 | 2433.01 | 64.08 | 2297.78 | 279.43 | 282.09 |
| 13.04 | 6034.58 | 5883.71 | 338.49 | 2335.48 | 65.86 | 2384.80 | 279.76 | 283.85 |
| 13.76 | 6614.30 | 6448.94 | 319.14 | 2249.85 | 67.52 | 2468.83 | 280.21 | 285.77 |
| 14.49 | 7207.84 | 7027.65 | 301.89 | 2173.51 | 69.05 | 2549.20 | 280.75 | 287.80 |
| 15.21 | 7814.15 | 7618.79 | 286.34 | 2104.11 | 70.45 | 2624.74 | 281.38 | 289.92 |
| 15.93 | 8432.08 | 8221.28 | 272.15 | 2039.22 | 71.72 | 2695.59 | 282.08 | 292.12 |
| 16.66 | 9060.39 | 8833.88 | 259.10 | 1976.38 | 72.84 | 2758.56 | 282.86 | 294.40 |
| 17.38 | 9697.69 | 9455.24 | 246.99 | 1913.74 | 73.79 | 2812.59 | 283.69 | 296.79 |
| 18.11 | 10342.54 | 10083.98 | 235.69 | 1850.27 | 74.58 | 2855.93 | 284.59 | 299.28 |
| 18.83 | 10993.53 | 10718.69 | 225.11 | 1785.93 | 75.20 | 2887.74 | 285.54 | 301.88 |
| 19.56 | 11649.30 | 11358.07 | 215.18 | 1721.44 | 75.68 | 2908.70 | 286.53 | 304.52 |
| 20.28 | 12294.47 | 11987.11 | 205.58 | 1644.50 | 74.76 | 2893.67 | 287.43 | 304.93 |
| 21.00 | 12940.78 | 12617.27 | 196.31 | 1532.33 | 73.75 | 2815.21 | 288.30 | 303.90 |
| 21.73 | 13581.90 | 13242.35 | 187.66 | 1450.31 | 73.83 | 2788.51 | 289.03 | 304.14 |
| 22.45 | 14223.64 | 13868.05 | 179.48 | 1377.49 | 73.85 | 2769.97 | 289.74 | 305.49 |
| 23.18 | 14864.68 | 14493.06 | 171.70 | 1307.86 | 73.66 | 2746.53 | 290.44 | 306.76 |
| 23.90 | 15503.62 | 15116.03 | 164.33 | 1241.11 | 73.32 | 2717.51 | 291.14 | 308.00 |
| 24.63 | 16139.26 | 15735.78 | 157.36 | 1179.33 | 72.93 | 2689.00 | 291.84 | 309.51 |
| 25.35 | 16770.81 | 16351.54 | 150.74 | 1118.97 | 72.41 | 2654.59 | 292.53 | 311.16 |
| 26.07 | 17397.80 | 16962.86 | 144.46 | 1061.74 | 71.84 | 2620.35 | 293.24 | 313.11 |
| 26.80 | 18019.24 | 17568.76 | 138.47 | 1005.04 | 71.16 | 2579.74 | 293.96 | 315.46 |
| 27.52 | 18634.59 | 18168.73 | 132.74 | 951.81 | 70.43 | 2542.04 | 294.71 | 318.19 |
| 28.25 | 19240.01 | 18759.01 | 127.02 | 839.54 | 68.59 | 2330.82 | 295.55 | 324.80 |
| 28.97 | 19826.22 | 19330.56 | 121.59 | 718.95 | 66.31 | 2051.98 | 296.52 | 331.98 |
| 29.70 | 20392.99 | 19883.16 | 116.54 | 619.08 | 64.15 | 1810.99 | 297.59 | 338.45 |
| 30.42 | 20941.12 | 20417.59 | 111.71 | 527.75 | 61.89 | 1576.05 | 298.74 | 345.12 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 31.14 | 21466.88 | 20930.20 | 107.14 | 456.22 | 59.75 | 1386.76 | 299.99 | 350.53 |
| 31.87 | 21976.23 | 21426.82 | 102.32 | 395.31 | 57.37 | 1218.81 | 301.21 | 355.23 |
| 32.59 | 22461.95 | 21900.40 | 96.51 | 333.69 | 54.18 | 1036.11 | 302.43 | 359.65 |
| 33.32 | 22923.61 | 22350.52 | 87.23 | 142.42 | 41.65 | 384.56 | 303.52 | 394.08 |
| 34.04 | 23378.80 | 22794.33 | 81.50 | 496.02 | 53.39 | 1666.45 | 303.81 | 300.88 |
| 34.76 | 23828.83 | 23233.11 | 72.77 | 479.30 | 50.01 | 1639.49 | 303.77 | 302.62 |
| 35.49 | 24239.37 | 23633.39 | 63.25 | 425.52 | 44.30 | 1467.50 | 303.73 | 301.13 |
| 36.21 | 24591.34 | 23976.56 | 51.95 | 357.90 | 35.79 | 1231.39 | 303.71 | 303.97 |
| 36.94 | 24904.64 | 24282.02 | 43.21 | 308.13 | 28.02 | 1054.17 | 303.56 | 305.04 |
| 37.66 | 25147.10 | 24518.42 | 42.92 | 301.60 | 27.78 | 1038.59 | 303.58 | 305.70 |
| 38.39 | 25387.56 | 24752.87 | 42.67 | 295.76 | 27.56 | 1024.71 | 303.60 | 306.20 |
| 39.11 | 25626.22 | 24985.57 | 42.43 | 290.39 | 27.35 | 1011.78 | 303.63 | 306.60 |
| 39.83 | 25863.10 | 25216.53 | 42.22 | 285.77 | 27.16 | 1001.02 | 303.65 | 306.82 |
| 40.56 | 26098.41 | 25445.95 | 42.03 | 281.48 | 26.98 | 990.82 | 303.68 | 306.96 |
| 41.28 | 26332.14 | 25673.83 | 41.85 | 277.36 | 26.81 | 980.55 | 303.71 | 307.09 |
| 42.01 | 26564.34 | 25900.23 | 41.68 | 273.41 | 26.63 | 970.36 | 303.74 | 307.19 |
| 42.73 | 26795.07 | 26125.19 | 41.52 | 269.70 | 26.46 | 960.60 | 303.77 | 307.24 |
| 43.46 | 27024.35 | 26348.74 | 41.38 | 266.25 | 26.30 | 951.39 | 303.80 | 307.23 |
| 44.18 | 27252.23 | 26570.92 | 41.25 | 263.10 | 26.14 | 943.00 | 303.83 | 307.15 |
| 44.90 | 27478.75 | 26791.78 | 41.14 | 260.04 | 25.99 | 934.57 | 303.86 | 307.06 |
| 45.63 | 27703.92 | 27011.32 | 41.03 | 257.12 | 25.84 | 926.36 | 303.88 | 306.93 |
| 46.35 | 27927.87 | 27229.67 | 40.94 | 254.73 | 25.70 | 920.10 | 303.91 | 306.64 |
| 47.08 | 28150.61 | 27446.85 | 40.86 | 252.11 | 25.56 | 912.49 | 303.93 | 306.44 |
| 47.80 | 28372.17 | 27662.87 | 40.79 | 250.13 | 25.43 | 907.43 | 303.95 | 306.03 |
| 48.53 | 28592.69 | 27877.87 | 40.73 | 248.25 | 25.31 | 902.55 | 303.96 | 305.59 |
| 49.25 | 28812.11 | 28091.81 | 40.68 | 246.21 | 25.19 | 896.63 | 303.97 | 305.22 |
| 49.97 | 29030.54 | 28304.77 | 40.65 | 244.80 | 25.08 | 893.39 | 303.98 | 304.62 |
| 50.70 | 29248.03 | 28516.83 | 40.62 | 243.26 | 24.97 | 889.25 | 303.98 | 304.08 |
| 51.42 | 29464.58 | 28727.96 | 40.60 | 242.00 | 24.87 | 886.22 | 303.98 | 303.43 |
| 52.15 | 29680.28 | 28938.27 | 40.59 | 240.92 | 24.77 | 883.86 | 303.97 | 302.72 |
| 52.87 | 29895.11 | 29147.73 | 40.59 | 239.73 | 24.67 | 880.72 | 303.96 | 302.05 |
| 53.60 | 30109.12 | 29356.39 | 40.60 | 238.85 | 24.58 | 878.92 | 303.95 | 301.26 |
| 54.32 | 30322.34 | 29564.28 | 40.61 | 237.87 | 24.48 | 876.45 | 303.92 | 300.51 |
| 55.04 | 30960.33 | 30186.32 | 54.49 | 803.07 | 105.28 | 3643.62 | 304.25 | 315.38 |
| 55.77 | 31865.08 | 31068.45 | 53.92 | 758.02 | 102.90 | 3518.05 | 304.62 | 319.15 |
| 56.49 | 32749.15 | 31930.42 | 53.40 | 706.80 | 100.53 | 3345.54 | 305.07 | 323.65 |
| 57.22 | 33620.37 | 32779.86 | 53.48 | 688.82 | 100.39 | 3332.84 | 305.57 | 323.88 |
| 57.94 | 34494.50 | 33632.14 | 53.70 | 680.06 | 100.76 | 3364.86 | 306.02 | 323.02 |
| 58.67 | 35372.98 | 34488.66 | 54.00 | 681.34 | 101.70 | 3449.93 | 306.42 | 320.89 |
| 59.39 | 36263.56 | 35356.97 | 54.38 | 691.75 | 103.23 | 3587.46 | 306.74 | 317.54 |
| 60.11 | 37167.17 | 36237.99 | 54.75 | 701.56 | 104.69 | 3724.63 | 306.96 | 314.30 |
| 60.84 | 38083.21 | 37131.13 | 55.11 | 710.53 | 106.09 | 3859.58 | 307.10 | 311.18 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 61.56 | 39011.17 | 38035.89 | 55.46 | 718.64 | 107.43 | 3991.75 | 307.16 | 308.18 |
| 62.29 | 39950.47 | 38951.71 | 55.80 | 725.99 | 108.71 | 4121.27 | 307.15 | 305.30 |
| 63.01 | 40900.68 | 39878.17 | 56.14 | 732.76 | 109.94 | 4248.77 | 307.08 | 302.51 |
| 63.74 | 41861.47 | 40814.94 | 56.48 | 739.24 | 111.15 | 4375.73 | 306.94 | 299.77 |
| 64.46 | 42832.67 | 41761.85 | 56.82 | 745.68 | 112.34 | 4503.58 | 306.75 | 297.05 |
| 65.18 | 43814.26 | 42718.90 | 57.17 | 752.40 | 113.54 | 4634.37 | 306.50 | 294.30 |
| 65.91 | 44806.35 | 43686.19 | 57.52 | 759.59 | 114.76 | 4769.27 | 306.20 | 291.51 |
| 66.63 | 45809.12 | 44663.89 | 57.88 | 767.31 | 116.00 | 4908.93 | 305.84 | 288.65 |
| 67.36 | 46822.80 | 45652.23 | 58.25 | 775.67 | 117.27 | 5054.16 | 305.44 | 285.73 |
| 68.08 | 47847.66 | 46651.47 | 58.62 | 784.48 | 118.56 | 5203.71 | 304.99 | 282.75 |
| 68.81 | 48883.48 | 47661.39 | 59.00 | 787.92 | 119.55 | 5292.28 | 304.48 | 280.44 |
| 69.53 | 49922.63 | 48674.57 | 59.21 | 773.30 | 119.57 | 5288.65 | 303.98 | 280.40 |
| 70.25 | 50961.95 | 49687.90 | 59.43 | 759.30 | 119.59 | 5284.90 | 303.50 | 280.35 |
| 70.98 | 52001.43 | 50701.39 | 59.66 | 745.86 | 119.61 | 5281.05 | 303.04 | 280.31 |
| 71.70 | 53041.07 | 51715.04 | 59.89 | 732.96 | 119.63 | 5277.08 | 302.59 | 280.27 |
| 72.43 | 54080.87 | 52728.85 | 60.13 | 720.57 | 119.65 | 5273.00 | 302.16 | 280.22 |

## 1.0 Improvements to ComPASS™

### 1.1 Implementation of Catamaran Resistance Model

The drag routine in ComPASS™ has been improved for catamarans, since the existing drag algorithms did not account for the increase in wave or form drag due to interference between the hulls. A multivariate regression analysis was performed on the model test data presented in "Resistance Experiments on a Series of High-Speed Displacement Catamaran Forms" by A. Molland, J. Wellicome, and P. Couser, RINA Transactions, Vol. 138, 1996. The regression resulted in a series of quadratic curves at a series of Froude numbers, using length-to-displacement and separation-to-length ratios as independent variables. The model tests only covered L/D ratios of {6.27, 7.4, 8.5, 9.5}, and s/L ratios of {0.2, 0.3, 0.4, 0.5}, so results for hull parameters outside these ranges are extrapolated. In addition, the models were run only at $0.2 < Fn < 1.0$. Therefore, for $Fn < 0.2$, the existing Holtrop method is used to determine the wave drag per demi-hull. In the range $0.2 < Fn < 0.35$ a linear blending function between Holtrop and the regression model is used, because of the poor correlation in the model data. For $0.35 < Fn < 1.0$, the regression model is used entirely, which accounts for both wave and form drag. Finally, for $Fn > 1.0$, the wave and form drag are extrapolated using an exponential curve fit.

#### 1.1.1 Approach

All versions of ComPASS™ prior to this upgrade (i.e. versions 329c and earlier) employed the same method of calculating the wave-making drag of twin-hull vessels. The wave resistance of a single hull is calculated according to the Holtrop-Mennen equations (or the Series 64 curve fits, if applicable), and then simply multiplied by two for both demi-hulls. The two major disadvantages of this approach are:

1. The separation between the hulls is not taken into account; consequently, the interaction effects of the two wave trains would be neglected.
2. The range of the data on which the equations are based limits the accuracy of the Holtrop-Mennen predictions.

One proposed solution to this problem was to implement a linearized wave-theory algorithm based on the writings of Michell, Lunde, Insel, Doctors, and others. However, there are disadvantages to this approach as well. Linearized wave-theory equations are complex and involve several nested integrals, usually highly oscillatory and requiring special techniques to solve. Approximations based on these equations are usually based on simplified hull geometry (parabolic shapes) and neglect the effects of transom stern and wave interaction in all but the most complex formulations [Ref. 2]. Such an approach was deemed

too time-consuming in terms of implementation and run-time to incorporate into ComPASS.

Instead, an empirical method based on Molland, Wellicome, and Couser was chosen. Their paper summarizes an experimental investigation of catamaran resistance components based on systematic variations of round-bilge hull forms. There are ten different hull forms modeled, comprising 3 variations of beam-to-draft ratio (B/T) and 4 length-to-displaced volume ratios ($L/\nabla^{1/3}$). The range of variables covered by the model test data is given in Table 1.

**Table 1 Range of Model Test Parameters**

| Model | L/B | B/T | L/∇1/3 |
|---|---|---|---|
| 3b | 7.0 | 2.0 | 6.27 |
| 4a | 10.4 | 1.5 | 7.40 |
| 4b | 9.0 | 2.0 | 7.41 |
| 4c | 8.0 | 2.5 | 7.39 |
| 5a | 12.8 | 1.5 | 8.51 |
| 5b | 11.0 | 2.0 | 8.50 |
| 5c | 9.9 | 2.5 | 8.49 |
| 6a | 15.1 | 1.5 | 9.50 |
| 6b | 13.1 | 2.0 | 9.50 |
| 6c | 11.7 | 2.5 | 9.50 |

In addition to the above parameters for the ten demi-hulls, the models were tested in a catamaran configuration at four different separation-to-length ratios (s/L): 0.2, 0.3, 0.4, 0.5 and at Froude numbers from 0.2 to 1.0. Using the resistance data given in the paper, it would be possible to construct a statistical model to predict residual resistance coefficient (CR) as a function of some combination of the independent variables. This model would be an equation of the form:

$$Cr = f\left( Fn, \frac{L}{\nabla^{1/3}}, \frac{B}{T}, \frac{s}{L} \right)$$

However, the exact nature of the equation would not be known until regression analyses were actually performed.

### 1.1.2 Discussion

The data presented in Reference 1 consists of tabulated values of Cr for five different hull configurations (monohull and the four separations) at Froude numbers 0.2,0.25,0.3 … 1.0. CR is defined therein as CT-CF, where CF is given

by the ITTC friction line. The tabular format expedited the organization of the data into standard regression models.

In a hull resistance problem such as this one, regression models are usually divided into two groups: speed-dependent and speed-independent models. In speed-independent models, ship speed or Froude number is not included as an independent variable, and separate resistance equations must be developed for discrete speeds. In speed-dependent models, therefore, speed is included as a dependent variable. The regression model used for this effort was a speed-independent model, chosen because of the difficulty in developing a non-linear regression model with so many independent terms, and because the data was already presented at discrete Froude numbers. Despite the high correlation that may be achieved at any single speed, the predicted values may not vary properly with speed, because resistance at a particular speed is not directly related to that at any other speed. However, given the closely spaced Froude numbers of the model test data, this effect should be diminished [Ref. 3].

After separating the resistance data by Froude number and sorting, several different forms of regression equations were attempted, to discern the effects of the variables and if any could be eliminated. According to the conclusions of Reference 1, it was determined that the effect of beam-to-draft ratio was inconsequential and could be omitted. The regression model that was finally chosen was a linear regression in two variables that also accounted for the interaction of the two:

$$C_R = b_0 + b_1 \cdot X1 + b_2 \cdot X1 + b_3 \cdot X1^2 + b_4 \cdot X2^2 + b_5 \cdot X1 \cdot X2\,,$$

where $X1= L/\nabla^{1/3}$, $X2=s/L$, and $b_n$ are the coefficients to be determined by regression. Substituting,

$$C_R = b_0 + b_1 \cdot \left(\frac{L}{\nabla^{1/3}}\right) + b_2 \cdot \left(\frac{s}{L}\right) + b_3 \cdot \left(\frac{L}{\nabla^{1/3}}\right)^2 + b_4 \cdot \left(\frac{s}{L}\right)^2 + b_5 \cdot \left(\frac{L}{\nabla^{1/3}}\right) \cdot \left(\frac{s}{L}\right)$$

Since the regression is a speed-independent model, there would be 17 different equations for $C_R$, one for each presented Froude number. The complete output of all 17 separate regressions is available upon request, while the $b_n$ coefficients are summarized in Table 2.

**Table 2 Regression and Correlation Coefficients**

| Fn | b0 | b1 | b2 | b3 | b4 | b5 | $R^2$ |
|---|---|---|---|---|---|---|---|
| 0.20 | 5.6647 | -0.4595 | -4.4858 | 0.0175 | 2.8200 | 0.2744 | 0.153 |
| 0.25 | 13.6393 | -2.2174 | -3.5136 | 0.1171 | -0.8500 | 0.4165 | 0.5020 |
| 0.30 | 13.2298 | -1.7212 | -4.2863 | 0.0738 | -1.2750 | 0.4629 | 0.8020 |
| 0.35 | 25.9152 | -3.7572 | -20.5341 | 0.1553 | 6.3775 | 1.6660 | 0.9650 |
| 0.40 | 30.6113 | -5.0530 | -4.2560 | 0.2258 | -8.2000 | 1.0653 | 0.9240 |
| 0.45 | 61.2023 | -10.6938 | -16.9298 | 0.4901 | -8.1600 | 2.1981 | 0.9810 |
| 0.50 | 93.0666 | -17.2119 | -41.7317 | 0.8430 | 10.0500 | 3.4654 | 0.9840 |
| 0.55 | 96.2020 | -17.7829 | -55.6999 | 0.8707 | 21.3850 | 4.2690 | 0.9760 |
| 0.60 | 79.3415 | -14.7414 | -43.6304 | 0.7283 | 18.9950 | 3.2103 | 0.973 |
| 0.65 | 52.1014 | -9.8132 | -16.8293 | 0.4999 | 10.1075 | 0.9686 | 0.984 |
| 0.70 | 43.2083 | -8.3629 | -8.1819 | 0.4369 | 5.5295 | 0.4254 | 0.9850 |
| 0.75 | 36.0321 | -7.0609 | -3.3955 | 0.3745 | 3.2032 | 0.1052 | 0.9840 |
| 0.80 | 31.2000 | -6.1575 | -1.2864 | 0.3301 | 2.2321 | -0.0299 | 0.9810 |
| 0.85 | 26.6632 | -5.3037 | 1.2892 | 0.2876 | 0.5629 | -0.1749 | 0.9760 |
| 0.90 | 23.3109 | -4.5947 | 1.3020 | 0.2491 | 0.2940 | -0.1504 | 0.9690 |
| 0.95 | 21.4507 | -4.3059 | 3.2468 | 0.2369 | -1.8865 | -0.2140 | 0.9540 |
| 1.00 | 19.5408 | -3.9405 | 3.9295 | 0.2189 | -2.3958 | -0.2545 | 0.9430 |

$R^2$ in the table is the regression correlation coefficient, which gives the quality of a least-squares fit to the original data. There is a high correlation with the experimental data (>90%) for all Froude numbers except 0.2, 0.25, and 0.3. This result could be due to increased scattering of the model test data at lower speeds. In addition to the relatively poor prediction capability of the regression equations at these Froude numbers, the model test data does not cover speeds lower than Fr=0.2 or above Fr=1.0. Two different approaches were employed to resolve these issues.

As Froude numbers increase toward 1.0, the data in the model test report suggested a decreasing contribution of separation ratio to model resistance in a general non-linear trend. The issue would be to develop an extrapolation equation for resistance as a function of both Froude number and length-displacement ratio. Examination of the data suggested an exponential function of the form $C_R = a \cdot \exp(Fn \cdot b)$, where a and b are themselves non-linear functions of length-displacement ratio, to be determined by examination. A plot of the CR data is shown in Figure 1, while the plot of the a and b coefficients is shown in Figure 2.

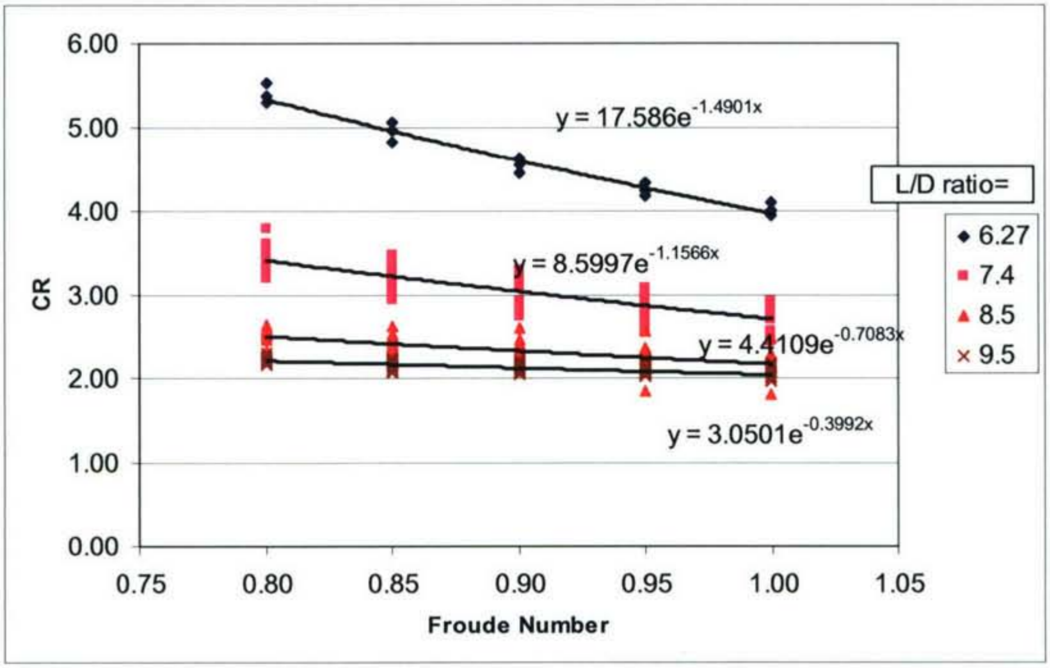


**Figure 1 $C_R$ Trends for High Froude Number**

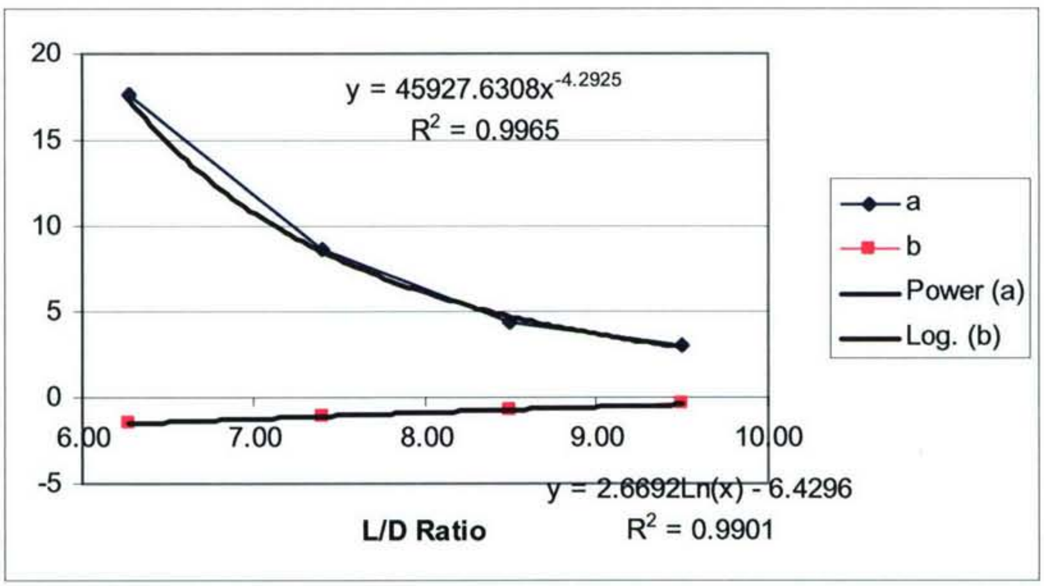


**Figure 2 Regression Coefficients**

By compiling the data from these two graphs, the final regression equation for Froude numbers greater than 1.0 is:

$$C_R(Fn > 1.0) = \left[45927.63 \cdot \left(\frac{L}{\nabla^{1/3}}\right)^{-4.2925}\right] \cdot \exp\left\{Fn \cdot \left[2.67 \cdot \log_e\left(\frac{L}{\nabla^{1/3}}\right) - 6.43\right]\right\}$$

For lower speeds, a similar extrapolation approach would not yield results as satisfactory as that at higher speeds because of the scattering in the original data. Therefore, it was decided to employ the existing Holtrop-Mennen equations, multiplying by two, for Froude numbers less than 0.2, and to develop a "blend" function between the two for Froude numbers greater than 0.2 and less than 0.35. This method would be similar to that used to develop the Series 64 resistance predictor [Ref. 4]:

1. Measure the difference between the drag calculated by both the regression equations and the Holtrop method at a Froude number of 0.35.
2. Calculate the wave drag at the current Froude number with the Holtrop method and multiply by two.
3. Use an interpolation to add the scaled difference between the two methods to the original Holtrop method:

$$C_R(0.2 \geq Fn > 0.35) = Holtrop + \left(\frac{Fn - 0.2}{0.35 - 0.2}\right) \cdot \Delta_{R-H}$$

### 1.1.3 Conclusions

The results of an off-line spreadsheet-based calculation are shown in Figure 3, Figure 4, and Figure 5. The different points represent the data as given in the model test report, while the curves are the results of the derived regression calculations. As can be seen, there is a relatively high correlation with the model tests, especially in the Froude numbers above approximately 0.6. In the range between Fn=0.35 and Fn=0.6, there is still a high correlation at each individual speed, but the exact shape over the speed range will not be portrayed. This effect is due to the nature of speed-independent regressions and to the spread in the model test data at Froude numbers of "peak" resistance values.

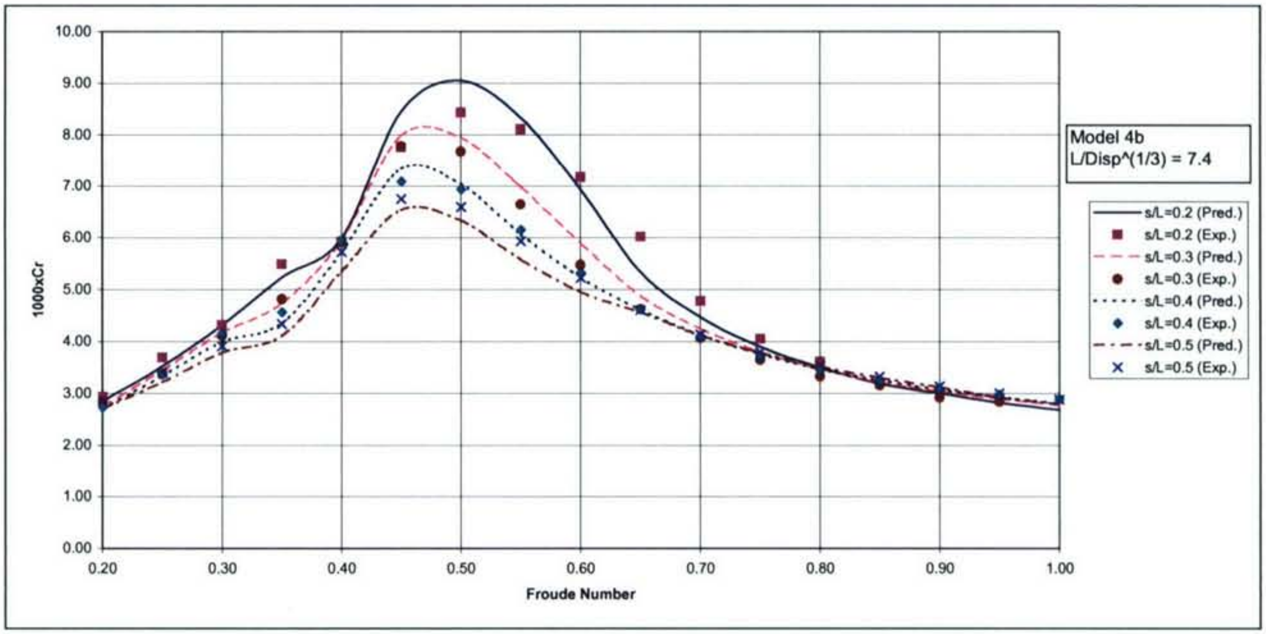


**Figure 3 Experimental vs. Predicted Catamaran Resistance for L/Δ = 7.4**

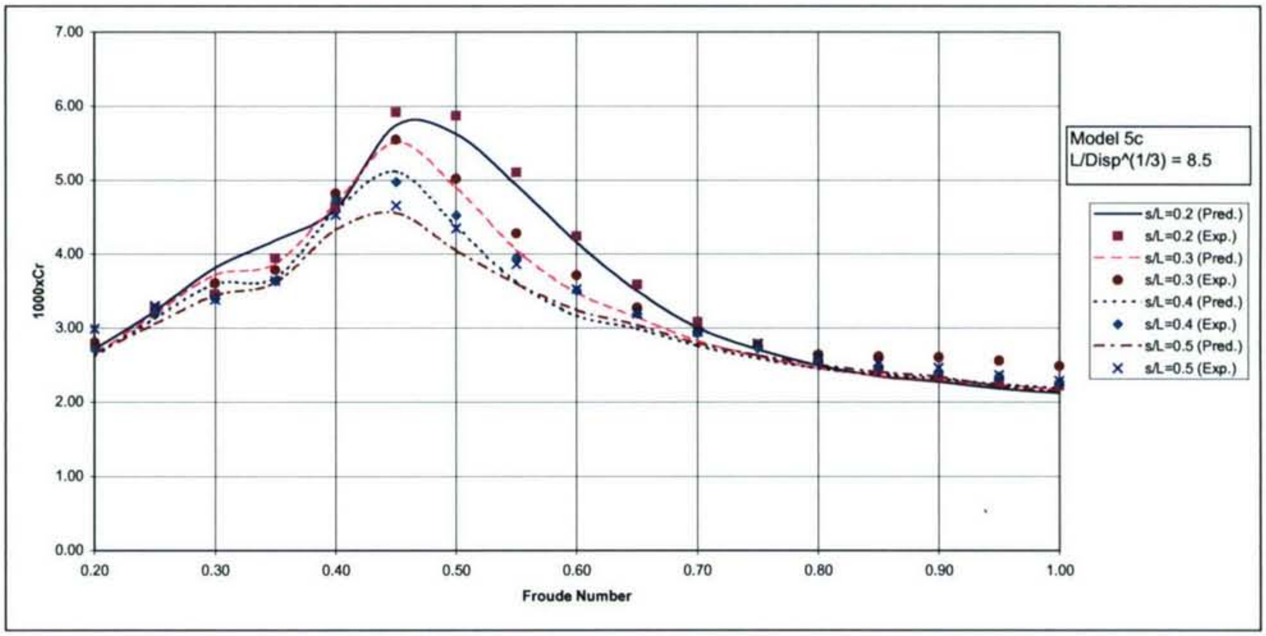


**Figure 4 Experimental vs. Predicted Catamaran Resistance for L/Δ = 8.5**

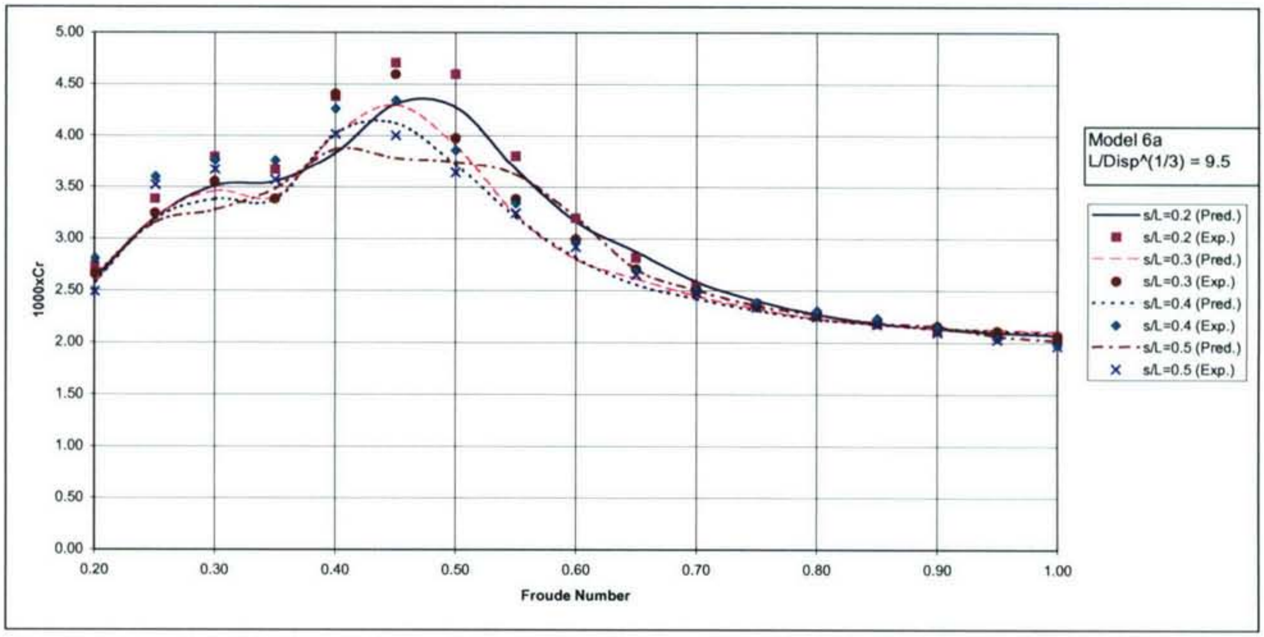


**Figure 5 Experimental vs. Predicted Catamaran Resistance for L/Δ = 9.5**

Finally, a test case was run to compare the residual (i.e. wave + form) drag results between the two calculations methods for a catamaran of nominal size. The test craft was an Incat 91m hullform modified to have an s/L ratio of 0.3 and L/∇ ratio of approximately 8.5. This test indicates that the regression approach yielded an increase of 16% over the Holtrop method, and shifts the peak to a higher Froude number, as shown in Figure 6. However, in the post-peak range, the Holtrop method predicts a steep drop-off followed by a slow increase, whereas the empirical approach predicts a smoother decline, which better matches the original model test data.

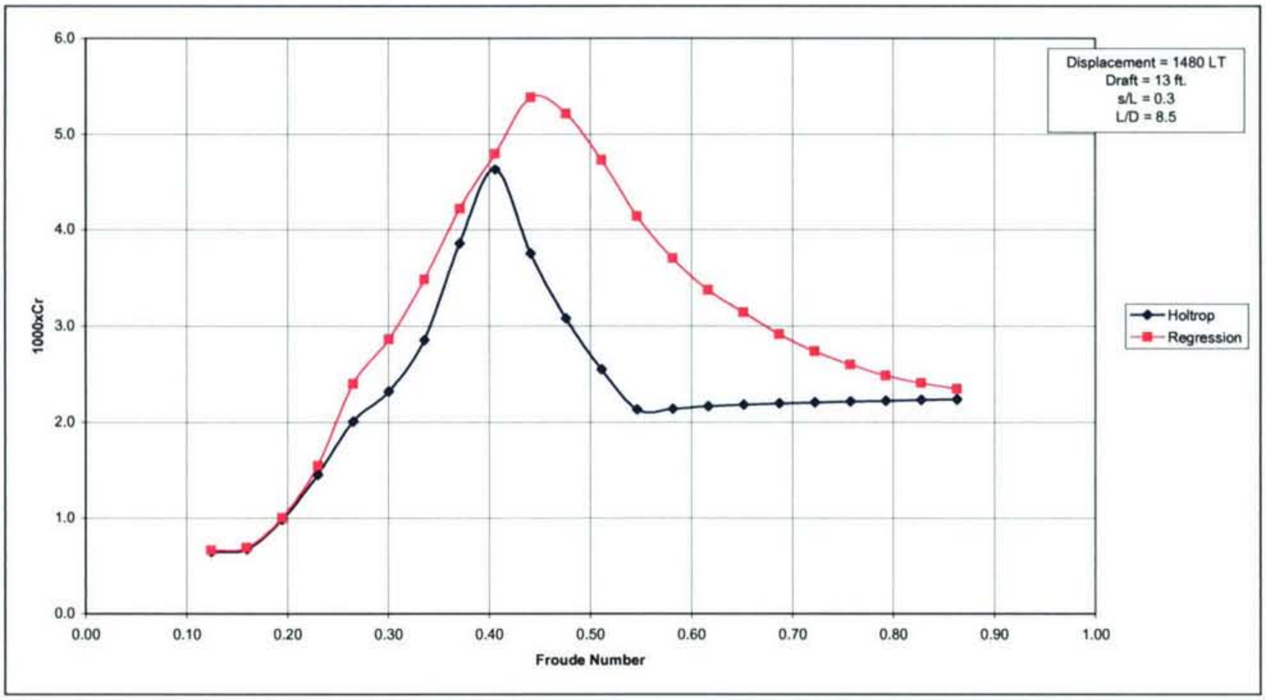


**Figure 6 Comparison of Holtrop vs. Regression Models**

### 1.1.4 References

1. Molland, A.F., Wellicome, J., and Couser, P. "Resistance Experiments on a Series of High-Speed Displacement Catamaran Forms." Ship Science Report No. 71, University of Southampton, 1994. Reprinted in RINA Transactions, Vol. 138, 1996.

2. Couser, P., J. Wellicome, and Molland, A.F. "An Improved Method for the Theoretical Prediction of the Wave Resistance of Transom-stern Hulls using a Slender Body Approach." International Shipbuilding Progress, Vol. 45, Number 444, December 1998.

3. Fung, S.C. and Leibman, L. "Revised Speed-Dependent Powering Predictions for High-Speed Transom Stern Hull Forms." FAST '95 Proceedings, Vol 1, Lübeck-Travemünde, Germany, September 1995.

4. "PASS™ Modification to Series 64 Drag." Band, Lavis and Associates Working Paper 913-35, April 2001.

1.2 Implementation of Improved Hull Form Description

In order to give the naval architect using ComPASS more flexibility in the definition of a hull form, the following changes were made to both the program code as well as the Human Computer Interface (HCI):

1. The number of discrete points per station has been increased from 10 to 15 to allow for greater flexibility in defining hull shapes.

2. The input for "keel flat width" has been changed from a dimensional to non-dimensional input, now specified as a ratio of the waterline beam.

Built on the above improvements, users now have the ability to input a "customized midship section", which is not dependent on midship section coefficient, keel flat, or deadrise angle. The designer can specify via the Input Screen shown in Figure 7 an arbitrary shape by supplying transverse ($y$) and vertical ($z$) coordinates, subject to the following limitations:

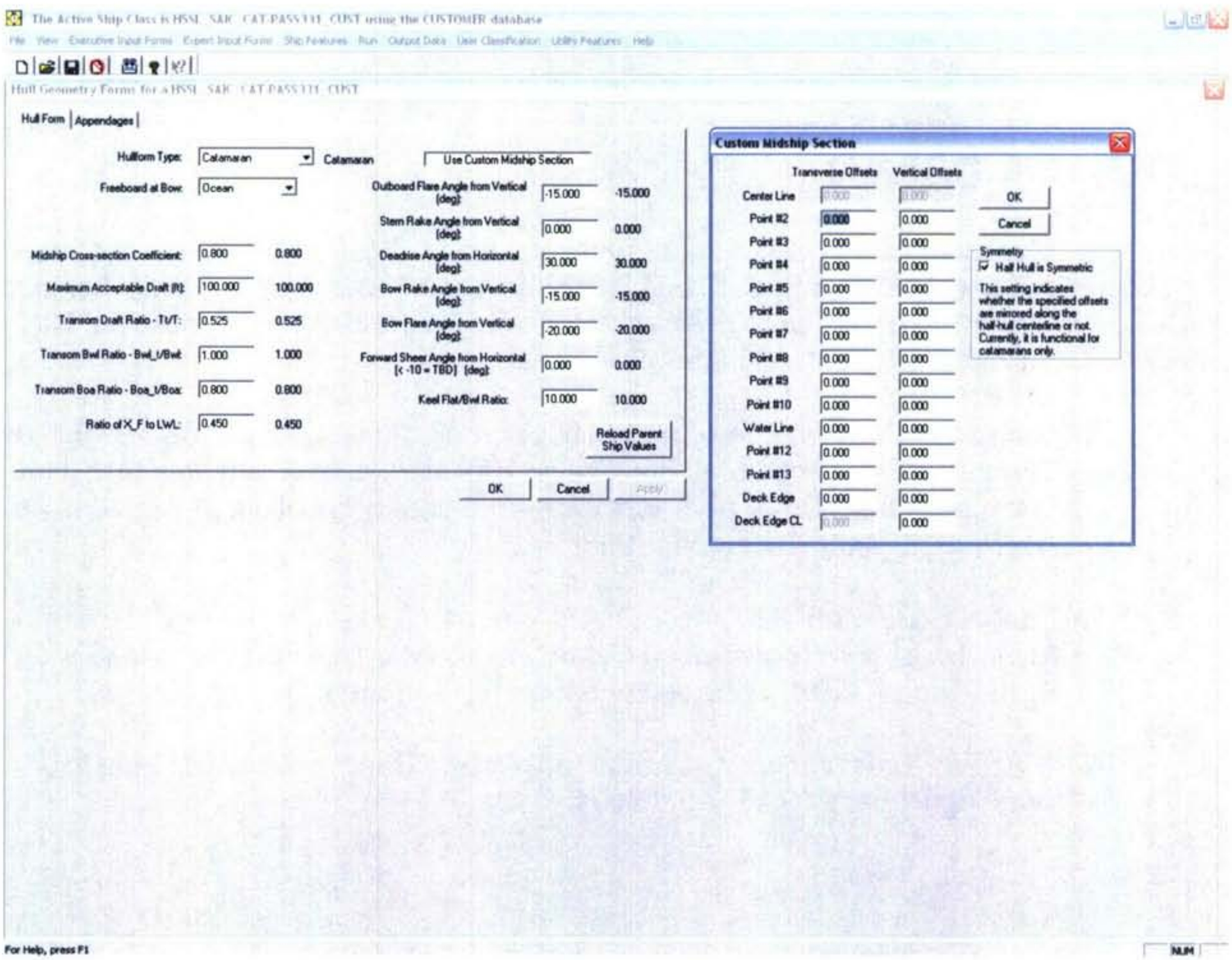


Figure 7 Custom Midship Section – Input Dialog Box

a) Transverse coordinates are expressed as a ratio to the hull waterline beam, which can be determined by dividing the waterline length by the length-to-beam ratio on the "Parametrics" input page shown in Figure 8 below.

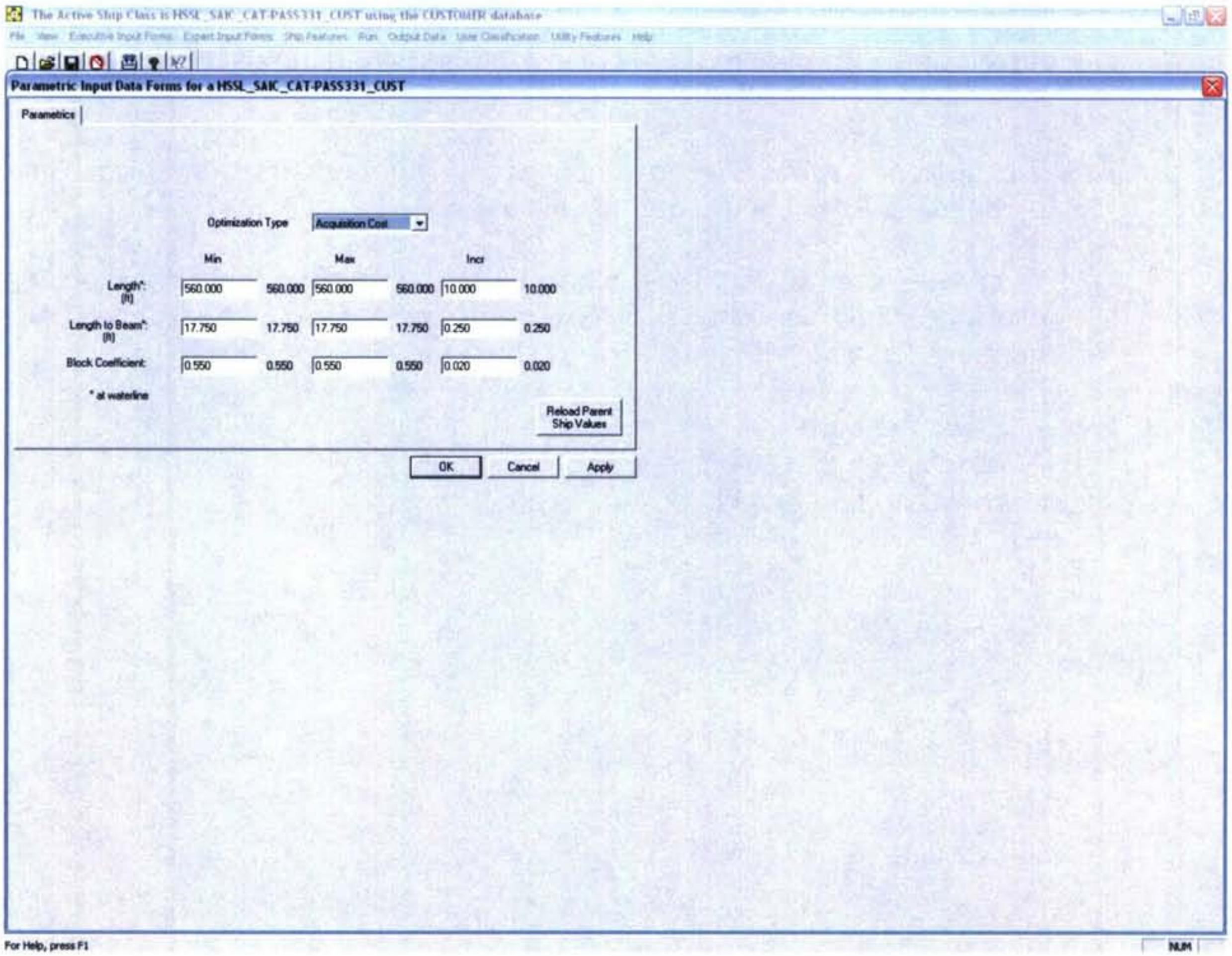


**Figure 8 Parametrics Input Page**

b) Vertical coordinates are expressed as a ratio to the design draft.

c) Several point locations, referring to Figure 7, are hard-coded in the program and cannot be changed.

i) ***Point 1*** must be centerline at the keel and must have coordinates (0,0).
ii) ***Point 11*** is the design waterline, so its vertical location should equal 1, but the transverse location is not fixed.
iii) ***Point 15*** must be at centerline at the main (weather) deck and must have a transverse value of 0, but its vertical location is not fixed.

iv) ***Point 14***, the deck edge, can have any transverse location, but its vertical location should be equal to point 15.

d) The specified midship offsets define a half-hull by default, which is then mirrored for a full hull. This behavior can be changed by clearing the check box for symmetric half-hull, shown below the "Cancel" button in Figure 7, but only asymmetric catamarans are allowed. The specified offsets define the entire demi-hull, which is then mirrored across the ship centerline.

e) The custom midship section input works for both the Graphical User Interface (GUI) as shown, and flat-file versions.

f) As can be seen in Figure 9, when using a custom midship section the following inputs on the Hull Geometry input form are disabled and therefore "grayed-out":

i) Bow freeboard
ii) Midship section coefficient, and
iii) Outboard flare angle.

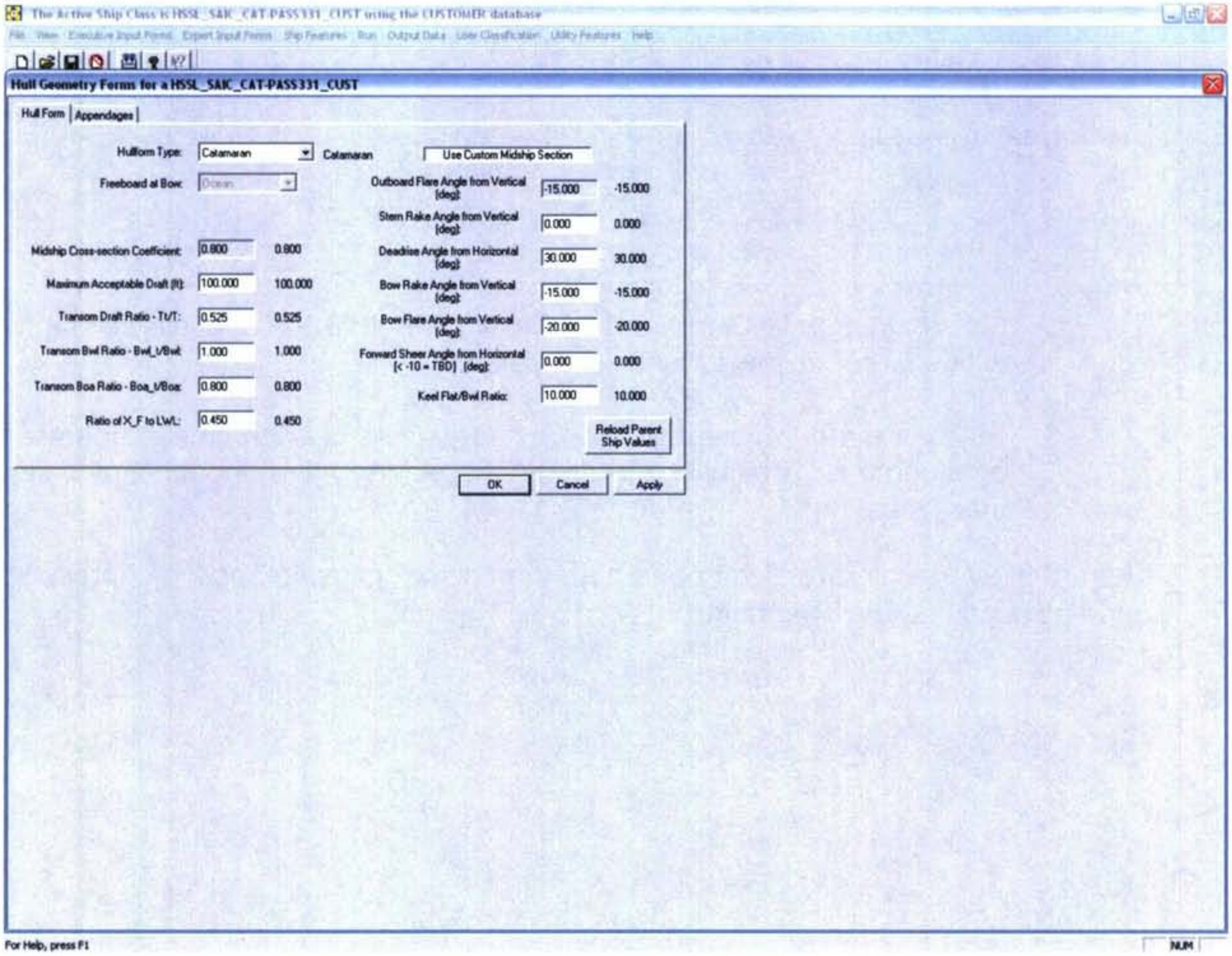


**Figure 9 Disabled Hull Form Inputs when using Custom Midship Section**

Deadrise angle and keel flat width are not disabled because they are still required to design the transom section, but have no effect on the midship section.

Changing the GUI to allow new user inputs necessitated an update to the customer and parent databases; consequently, databases used in ComPASS versions 330 and older will not function in version 331.

File importing and exporting has been updated to accommodate the new inputs, however, the first line of the text file (or flat file) must be modified to reflect the version number:

**"PASS331" instead of "PASS2"**

The custom midship section inputs go on a single line at the end of the file, following the single header line shown:

**"******** Custom Midship Section ********"**

(*Note: the number of stars is not important*).

The format of the input line is:

```
N; [y1,z1;y2,z2;…;y15;z15]
```

Where:

- N is an integer, either 0 or 1, indicating whether the midship section is active or not, followed by a semi-colon.
- *y*1, *z*1 are the transverse, vertical coordinates of each point, separated by a comma. A semi-colon must separate the pairs of points, of which there must be 15.

The flat-file version correctly imports both the custom midship section, if present, and any specified SWBS inputs.

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May 1, 2007

Dr. Patrick Purtell, ONR Code 331
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

Subject: Report No. 831.001-1

Reference: Contract No. N00014-06-M-0156

Dear Dr. Purtell:

Enclosed please find our Report No. 831.001-1 entitled "Concept Design Report for a Low Draft Stabilized – High Speed Connector (LDS-HSC) Vessel for The ONR High Speed Sea Lift (HSSL) Program."

Please feel free to contact me or David Lavis if you have any questions of a contractual nature. All technical questions should be directed to Mr. Volker Stammnitz or Mr. Chris Clayson.

Sincerely,

CDI MARINE COMPANY
*Systems Development Division*

Tosha L Christopolus

Ms. Tosha Christopolus
Manager – Administration and Projects

TC/dk
Enclosures

cc: Ms. Emily McLaughlin, ONR (letter & SF-298 only)
Defense Technical Information Center (w/ all enclosures)
Director, Naval Research Lab (w/ all enclosures)